PA. ENT COOPERATION TREA .

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 06 March 2001 (06.03.01)	
International application No. PCT/JP00/03118	**Applicant's or agent's file reference** 99R00169
International filing date (day/month/year) 15 May 2000 (15.05.00)	**Priority date** (day/month/year) 15 May 1999 (15.05.99)
Applicant ACOSTA, Elizabeth, Jane et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   11 December 2000 (11.12.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

   [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer R. Forax Telephone No.: (41-22) 338.83.38

International application No. PCT/JP00/03118
International filing date: 15/05/2000

Applicant: SHARP KABUSHIKI KAISHA
22-22 Nagaikecho, Abeno-ku, Osaka-shi
Osaka 545-9522 Japan

European Patent Office (IPEA/EP)
D-80298 Munnich
GERMANY
ATTEN: Examiner

AMENDMENT UNDER ARTICLE 34
AND REPLY TO WRITTEN OPINION

Dear Sirs:

This is in response to the first Written Opinion dated August 8, 2001.

1. Regarding Claim Amendments

Claims 1, 16 and 21 are amended so as to be in two-part form in accordance with Rule 6.3(b) PCT.

Claim 2 has been cancelled.

Claim 5 has been amended to incorporate the subject matter of claim 6.

Claim 6 has been cancelled.

Claim 14 has been amended to incorporate the subject matter of claim 15.

Claim 15 has been cancelled.

Claim 23 has been amended to incorporate the subject matter of claim 24.

Claim 24 has been cancelled.

2. Regarding Novelty and Inventive Step (Item V)

Regarding Claim 1 and Claim 21

10/031654
SHUSAKU YAMAMOTO
831 Rec'd PCT/PTC 13 NOV 2001
PCT/JP00/03118

Claims 1 and 21 claim at least one retarder comprising a Bistable Twisted Nematic liquid crystal. Bistable Twisted Nematic devices switch between two states, a high twist and a low or zero twist state. In the low twist state, the local optic axis is primarily in the plane of the retarder, but twists substantially linearly from one surface to the other through an angle ϕ. In a high twist state, the local optic axis is primarily in the plane of the retarder but twists substantially linearly from one surface to the other through an angle of, for example, $\phi\pm360$ in the device described in EP0018180, or $\phi\pm180$ in the device of Appl. Phys. Lett. 70(9)3.

D2 does not disclose at least one retarder comprising a Bistable Twisted Nematic Liquid Crystal. D2 discloses, in the paragraph bridging page 8-9, a nematic <u>out-of-plane</u> liquid crystal whose optic axis is switched in and out of the plane of the retarder so as to vary the retardation. The optic axis of a Bistable Nematic Liquid Crystal is in the plane of the retarder regardless of which state it is in. Furthermore, a Bistable Twisted Nematic Liquid Crystal is not a variable tuning retarder as it has two metastable states.

D2 hence does not teach or suggest at least one retarder comprising a Bistable Twisted Nematic Liquid Crystal.

<u>3. Regarding Defects in the International Application (Item VII)</u>

<u>3.1</u>
Independent claims 1, 16 and 21 are appropriately amended so as to be in the two-part form in accordance with Rule 6.4(b) PCT.

<u>3.2</u>
There exist no appropriate reference symbols to be provided for the features of the claims.

<u>3.3</u>
It is assumed that claim 16 is correctly objected to in view of claims 1, 3 and 4 rather than in view of claims 1-3.

Claim 16 recites a second state in which the retardation is substantially zero. Such subject matter is not claimed in

any of claims 1, 3 and 4. Specifically, claim 3 claims a second state in which it does not rotate linearly polarised light, and, claim 4 claims a second state in which it does not convert linearly polarised light to circularly polarised light. Neither one of these states require having substantially zero retardation.

Claim 16 hence does not comprise all the features of claims 1, 3 and 4 and is therefore not redundant.

4. Regarding Clarity Rejections (Item VIII)

4.1

Claim 5 is amended to incorporate the subject matter of claim 6, hence clearly defining the parameter "x".

Claim 14 is amended to incorporate the subject matter of claim 15, hence clearly defining the parameter "x".

Claim 23 is amended to incorporate the subject matter of claim 24, hence clearly defining the parameter "x".

The function $\theta(\phi)$ is defined in columns 2 and 3 of Figure 3 and hence is clearly defined.

4.2

The range of parameter y as claimed in claim 2 ($0.8<y< 1.3$) is not supported in the description. Claim 2 is cancelled.

Support for the range of parameter y in claim 1 ($0.7<y<1.3$) can be found in the last paragraph of page 3 of the description.

Respectfully submitted

Date: 04.09.2001

7828 Patent Attorney
YAMAMOTO Shusaku

Shusaku Yamamoto Patent Law Offices
15th Floor Crystal Tower,
2-27, Shiromi 1-chome

Chuo-ku, Osaka-shi
Osaka 540-6015 Japan

Attachment: Replacement pages 29-33.

repl. by amdt 34

CLAIMS

1. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein, in at least one state of the device, a first of said retarders acts to rotate linearly polarised light of wavelength λ and a second of the retarders acts to convert linearly polarised light of wavelength $y\lambda$ (where $0.7<y<1.3$) to substantially circular polarised light, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal.

2. A device according to claim 1, wherein $0.8<y<1.3$.

3. A device according to claim 1, wherein the BTN is switchable between a first state in which it rotates linearly polarised light and a second state in which it does not rotate linearly polarised light.

4. A device according to claim 1, wherein the BTN is switchable between a first state in which it substantially converts linearly polarised light to circularly polarised light and a second state in which it does not convert linearly polarised light to circularly polarised light.

5. A device according to any one of claims 1 to 4, wherein the retarder adjacent to the polariser is a fixed retarder with an optic axis at an angle θ_1 to either the transmission or absorption axis of the polariser, and the retarder adjacent to the reflector is a BTN which in the low twist state, ϕ, has the input director (LC director at cell surface adjacent to retarder) at an angle $\theta_2 = 2\theta_1+\theta\ (\phi)\ +x$.

6. A device according to claim 5, wherein $x < 5°$.

7. A device according to claim 5 or 6, wherein θ_1 is substantially 15° and the low twist state is substantially $\phi = 0°$.

8. A device according to claims 5 or 6, wherein $5° < \theta_1 < 25°$ and the low twist state is substantially $\phi = 63.6°$.

9. A device according to claim 5 or 6, wherein $\theta_1 = 15°$ and the low twist state is substantially $\phi = 63.6°$.

10. A device according to claim 8, wherein $\theta_1 = 6°$ and the low twist state is substantially $\phi = 63.6°$.

11. A device according to claims 4 or 5, wherein $5° < 90° - \theta_1 < 25°$ and the low twist state is substantially $\phi = 63.6°$.

12. A device according to claim 11, wherein $\theta_1 = 84°$ and the low twist state is substantially $\phi = 63.6°$.

13. A device according to claim 5, wherein θ_1 and θ_2 are both substantially 15° and the low twist state is substantially $\phi = 85°$.

14. A device according to claim 1 or 2, wherein the retarder adjacent to the polariser is a BTN which in the low twist state has $\phi = 0°$ and optic axis at an angle α to either the transmission or absorption axis of the polariser and the retarder adjacent the reflector is a fixed retarder with optic axis at an angle $2\alpha + 45° + x$.

15. A device according to claim 14, wherein $x < 5°$, preferably 0°.

16. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein a first of said retarders provides a retardation of substantially $m\lambda/2$ and a second of the retarders provides a retardation of substantially $n\lambda/4$ where m is an integer and n is an odd integer, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between a first state in which the retarder provides a retardation of substantially $m\lambda/2$ or $n\lambda/4$ and a second state in which the retardation is substantially zero.

17. A device according to claim 16, wherein the wavelength λ is an operating wavelength of the reflective liquid crystal device and is in the range 400-700nm.

18. A device according to claim 17, wherein the wavelength λ is in the range 420-600nm.

19. A device according to claim 18, wherein the wavelength λ is in the range 440-550nm.

20. A device according to any of claims 16 to 19, wherein the retarder comprising a BTN liquid crystal provides a retardation of $n\lambda/4$.

21. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising at least three retarders, and a reflector,

wherein at least one of said retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between first and second retardation states.

22. A device according to claim 21, wherein the retarder adjacent to the reflector acts to convert linearly polarised light of wavelength $y\lambda$ $(0.7<y<1.3)$ to substantially circular polarised light, and the two other retarders act to rotate linearly polarised light of wavelength λ.

23. A device according to claim 22, wherein the retarder adjacent the polariser is at angle α to the axis of the polariser, the next retarder is at angle β to the axis of the polariser and the retarder adjacent the reflector is a BTN which in the low twist state, ϕ, has the input director (LC director at cell surface adjacent to retarder) at an angle $2(\beta-\alpha) + \theta(\phi)+x$ to the axis of the polariser.

24. A device according to claim 23, wherein $x < 5°$, preferably $0°$.

25. A device according to claim 24 in which $\alpha = 6.9°$ and $\beta = 34.5°$.

26. A device according to claim 21, wherein the retarder adjacent to the polariser acts to rotate linearly polarised light of wavelength λ, the middle retarder acts to convert linearly polarised light of wavelength $y\lambda$ $(0.7<y<1.3)$ to substantially circular polarised light, and the retarder adjacent to the reflector is a BTN device.

27. A device according to claim 26, wherein the retarder adjacent to the polariser has optic axis at α to the axis of the polariser, the middle retarder has optic axis at $2\alpha+45°$ to the axis of the polariser.

28. A device according to claim 27, wherein $\alpha=15°$ and the BTN has a low twist state of 0° orientated at 75° to the transmission axis of the polariser.

29. A device according to claims 21, wherein said at least one retarder provides a retardation in said first state of substantially $m\lambda/2$ or $n\lambda/4$ where m is an integer and n is an odd integer, and a retardation in said second state of substantially zero.

30. A device according to claims 22 to 29, wherein the wavelength λ is an operating wavelength of the reflective liquid crystal device and is in the range 400-700nm.

31. A device according to claim 30, wherein the wavelength λ is in the range 440-550nm.

32. A device according to any of the preceding claims in which the BTN switches between a state ϕ and $(\phi\pm360°)$.

33. A device according to any of the preceding claims in which the BTN switches between a state ϕ and $(\phi\pm180°)$.

TENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 99R00169	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/JP 00/03118	International filing date *(day/month/year)* 15/05/2000	(Earliest) Priority Date *(day/month/year)* 15/05/1999
Applicant SHARP KABUSHIKI KAISHA et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).
4. With regard to the **title,**
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:
5. With regard to the **abstract,**
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 11
   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/JP 00/03118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/139 G02F1/1347 G02B5/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F G02B H04N G09G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 869 470 A (SHARP KK) 7 October 1998 (1998-10-07) column 4, line 46 - line 55 column 10, line 8 -column 11, line 11; figures 11-13	1,4,16
Y		3,5,21

Y	GB 2 318 878 A (SHARP KK) 6 May 1998 (1998-05-06) cited in the application page 7, paragraph 9 -page 10, paragraph 3 page 12, paragraph 3 -page 15, paragraph 1; figures 1,2,7,10-13	3,5,21
A		1,16

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2001	24/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Manntz, W

1

International Application No
PCT/JP 00/03118

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	TILLIN M ET AL: "REFLECTIVE SINGLE POLARISER LOW AND HIGH TWIST LIQUID-CRYSTAL DISPLAYS" SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS,US,SANTA ANA, CA: SID, vol. 29, 1998, pages 311-314, XP002129021 ISSN: 0098-966X the whole document	1,3,4, 16,21
A	US 5 658 490 A (SHARP GARY D ET AL) 19 August 1997 (1997-08-19) column 12, line 13 -column 13, line 66; figures 12A,12B,14	1,16,21
A	US 5 627 666 A (SHARP GARY D ET AL) 6 May 1997 (1997-05-06) column 8, line 56 -column 9, line 32; figure 8	1,16,21
E	WO 00 36462 A (COLORLINK INC) 22 June 2000 (2000-06-22) page 37, line 12 -page 41, line 10; figures 12A,12B,19A,19B,23C	1-5,16, 21-23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/JP 00/03118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0869470 A	07-10-1998	GB 2323956 A	07-10-1998
		JP 10325945 A	08-12-1998
		US 6104368 A	15-08-2000
GB 2318878 A	06-05-1998	EP 0840160 A	06-05-1998
		JP 10161112 A	19-06-1998
		KR 256434 B	15-05-2000
		US 6204904 B	20-03-2001
US 5658490 A	19-08-1997	AU 5531196 A	23-10-1996
		CA 2217712 A	10-10-1996
		EP 0820495 A	28-01-1998
		JP 11503247 T	23-03-1999
		WO 9631577 A	10-10-1996
		US 6078374 A	20-06-2000
		US 6183091 B	06-02-2001
		US 2001000971 A	10-05-2001
		US 6046786 A	04-04-2000
US 5627666 A	06-05-1997	US 6141069 A	31-10-2000
WO 0036462 A	22-06-2000	US 6078374 A	20-06-2000
		AU 2481000 A	03-07-2000
		US 6183091 B	06-02-2001
		US 2001000971 A	10-05-2001

1003165P

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 November 2000 (23.11.2000)

PCT

(10) International Publication Number
WO 00/70394 A3

(51) International Patent Classification[7]: G02F 1/139, 1/1347, G02B 5/30

(21) International Application Number: PCT/JP00/03118

(22) International Filing Date: 15 May 2000 (15.05.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9911246.8 15 May 1999 (15.05.1999) GB

(71) Applicant (*for all designated States except US*): **SHARP KABUSHIKI KAISHA** [JP/JP]; 22-22, Nagaikecho, Abeno-ku, Osaka-shi, Osaka 545-8522 (JP).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **ACOSTA, Elizabeth, Jane** [GB/GB]; 20 The Garth, Botley, Oxford, Oxfordshire OX2 9AL (GB). **TILLIN, Martin, David** [GB/GB]; 11 Summer Fields, Abingdon, Oxfordshire OX14 2PG (GB). **TOWLER, Michael, John** [GB/GB]; 20 The Garth, Botley, Oxford, Oxfordshire OX2 9AL (GB).

(74) Agent: **YAMAMOTO, Shusaku**; Fifteenth Floor, Crystal Tower 2-27, Shiromi 1-chome, Chuo-ku, Osaka-shi, Osaka 540-6015 (JP).

(81) Designated States (*national*): JP, KR, US.

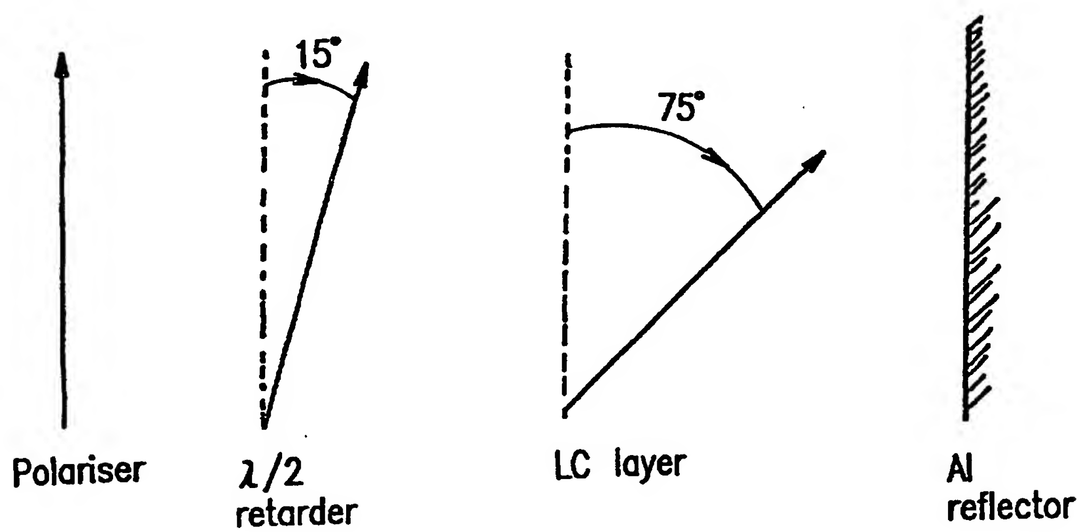
(84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *with international search report*

(88) Date of publication of the international search report: 21 March 2002

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: REFLECTIVE LIQUID CRYSTAL DEVICES



(57) Abstract: A reflective liquid crystal device comprises in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector. A first of the retarders provides a retardation of $m\lambda/2$ and a second of the retarders provides a retardation of n(/4, where m is an integer and n is an odd integer, and wherein at least one of the first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal. This BTN retarder is switchable between a first state in which the retarder provides a retardation of $m\lambda/2$ or $n\lambda/4$ and a second state in which the retardation is zero.

WO 00/70394 A3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/JP 00/03118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/139 G02F1/1347 G02B5/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F G02B H04N G09G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 869 470 A (SHARP KK) 7 October 1998 (1998-10-07) column 4, line 46 - line 55 column 10, line 8 -column 11, line 11; figures 11-13	1,4,16
Y		3,5,21

Y	GB 2 318 878 A (SHARP KK) 6 May 1998 (1998-05-06) cited in the application page 7, paragraph 9 -page 10, paragraph 3 page 12, paragraph 3 -page 15, paragraph 1; figures 1,2,7,10-13	3,5,21
A		1,16

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2001	24/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Manntz, W

1

International Application No
PCT/JP 00/03118

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TILLIN M ET AL: "REFLECTIVE SINGLE POLARISER LOW AND HIGH TWIST LIQUID-CRYSTAL DISPLAYS" SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS,US,SANTA ANA, CA: SID, vol. 29, 1998, pages 311-314, XP002129021 ISSN: 0098-966X the whole document ---	1,3,4, 16,21
A	US 5 658 490 A (SHARP GARY D ET AL) 19 August 1997 (1997-08-19) column 12, line 13 -column 13, line 66; figures 12A,12B,14 ---	1,16,21
A	US 5 627 666 A (SHARP GARY D ET AL) 6 May 1997 (1997-05-06) column 8, line 56 -column 9, line 32; figure 8 ---	1,16,21
E	WO 00 36462 A (COLORLINK INC) 22 June 2000 (2000-06-22) page 37, line 12 -page 41, line 10; figures 12A,12B,19A,19B,23C -----	1-5,16, 21-23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/JP 00/03118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0869470 A	07-10-1998	GB 2323956 A	07-10-1998
		JP 10325945 A	08-12-1998
		US 6104368 A	15-08-2000
GB 2318878 A	06-05-1998	EP 0840160 A	06-05-1998
		JP 10161112 A	19-06-1998
		KR 256434 B	15-05-2000
		US 6204904 B	20-03-2001
US 5658490 A	19-08-1997	AU 5531196 A	23-10-1996
		CA 2217712 A	10-10-1996
		EP 0820495 A	28-01-1998
		JP 11503247 T	23-03-1999
		WO 9631577 A	10-10-1996
		US 6078374 A	20-06-2000
		US 6183091 B	06-02-2001
		US 2001000971 A	10-05-2001
		US 6046786 A	04-04-2000
US 5627666 A	06-05-1997	US 6141069 A	31-10-2000
WO 0036462 A	22-06-2000	US 6078374 A	20-06-2000
		AU 2481000 A	03-07-2000
		US 6183091 B	06-02-2001
		US 2001000971 A	10-05-2001

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G02F 1/13

A2

(11) International Publication Number: WO 00/70394

(43) International Publication Date: 23 November 2000 (23.11.00)

(21) International Application Number: PCT/JP00/03118

(22) International Filing Date: 15 May 2000 (15.05.00)

(30) Priority Data:
9911246.8 15 May 1999 (15.05.99) GB

(71) Applicant *(for all designated States except US)*: SHARP KABUSHIKI KAISHA [JP/JP]; 22-22, Nagaikecho, Abeno-ku, Osaka-shi, Osaka 545-8522 (JP).

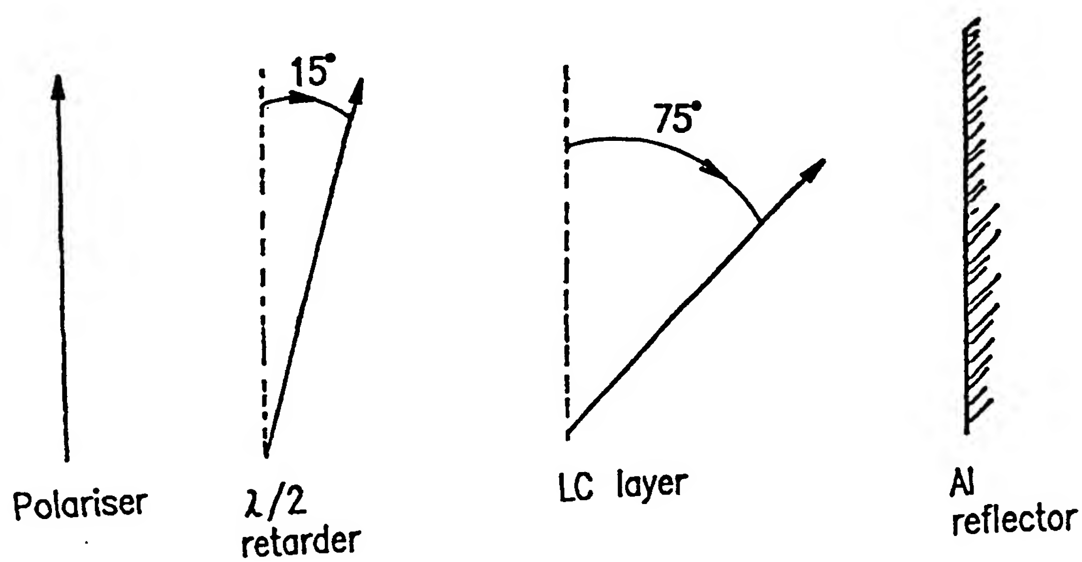
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: ACOSTA, Elizabeth, Jane [GB/GB]; 20 The Garth, Botley, Oxford, Oxfordshire OX2 9AL (GB). TILLIN, Martin, David [GB/GB]; 11 Summer Fields, Abingdon, Oxfordshire OX14 2PG (GB). TOWLER, Michael, John [GB/GB]; 20 The Garth, Botley, Oxford, Oxfordshire OX2 9AL (GB).

(74) Agent: YAMAMOTO, Shusaku; Fifteenth Floor, Crystal Tower 2-27, Shiromi 1-chome, Chuo-ku, Osaka-shi, Osaka 540-6015 (JP).

(81) Designated States: JP, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: REFLECTIVE LIQUID CRYSTAL DEVICES



(57) Abstract

A reflective liquid crystal device comprises in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector. A first of the retarders provides a retardation of $m\lambda/2$ and a second of the retarders provides a retardation of n(/4, where m is an integer and n is an odd integer, and wherein at least one of the first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal. This BTN retarder is switchable between a first state in which the retarder provides a retardation of $m\lambda/2$ or $n\lambda/4$ and a second state in which the retardation is zero.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

DESCRIPTION

REFLECTIVE LIQUID CRYSTAL DEVICES

TECHNICAL FIELD

The present invention relates to reflective liquid crystal devices and more particularly to reflective liquid crystal display devices comprising a bistable twisted nematic (BTN) liquid crystal.

BACKGROUND ART

Reflective liquid crystal devices typically comprise a linear polariser and a mirror, with one or more retarders and a switchable liquid crystal element sandwiched between the polariser and the mirror. In a first state of the liquid crystal element, linearly polarised light passing through the polariser is reflected from the mirror and arrives back at the polariser with the same linear polarisation. Hence the reflected light is transmitted by the polariser and the device appears in the bright state. In a second state of the liquid crystal element, linearly polarised light is converted to have a circular polarisation such that upon reflection at the mirror the "handedness" of the circular polarisation is changed (i.e. from right to left or from left to right). Light arriving back at the polariser is arranged to have a polarisation angle 90° shifted from the axis of the polariser (either the transmission or the absorption axis of the polariser may be considered and both give identical results). Hence, the reflected light is not transmitted by the polariser and the device appears in the dark state. Reflective liquid crystal devices are attractive particularly for

low power consumption applications.

GB9622733.5 describes a reflective liquid crystal display device comprising a polariser and a mirror between which are disposed several retarders. One of the retarders is a liquid crystal element whose optic axis is switchable so as to switch the device between a reflective state and a non-reflective state.

EP0018180 describes a liquid crystal cell comprising a cholesteric liquid crystal. The liquid crystal is bistable and can exist in either one of its two metastable states until specific steps are taken to cause a transition to the other metastable state. Energy is expended only when a transition occurs.

The article "Bistable Twisted Nematic Mode with One Polariser for Reflective Liquid Crystal Displays", Kim, Yu & Lee, IDRC Asia Display 98, Seoul, Korea, p 763, describes a device having in sequence an input linear polariser, a quarter wave retarder, a BTN element, and a mirror.

The article "Reflective Bistable Twisted Nematic Liquid Crystal Display", Xie & Kwok, Jpn J. Appl. Phys, Vol37, part 1, No. 5a (1998), p 2572, describes a device having an input polariser, a BTN mode and a reflector. The proposed device does not include any additional retarders and states that the contrast ratio measured is about 6:1.

WO98/48320 describes a reflective liquid crystal display device comprising a polariser and a mirror between

which are disposed a half wave retarder, a quarter wave retarder, and a liquid crystal element.

Abstract 39.3 (published in the SID 1999 International Symposium, Seminar & Exhibition -Advance program, in advance of a conference to be held in San Jose, CA, USA, May 16-21 1999) titled "Reflective Single-Polariser Bistable Nematic LCD with Optimum Twist", Y.J. Kim & J.S. Patel, describes a single-polariser reflective LCD having a bistable twisted nematic mode. The twist angles of the two bistable states are 63.6° and 423.6°.

The article "Fast bistable nematic display using monostable surface switching", I. Dozov, M. Nobili and G. Durand, Appl. Phys. Lett. 70 (9), 3 March 1997, describes a device having a two bistable states, namely a metastable uniform (untwisted) state and a half-turn (180°) twist state.

DISCLOSURE OF THE INVENTION

According to a first aspect of the present invention there is provided a reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein, in at least one state of the device, a first of said retarders acts to rotate linearly polarised light of wavelength λ and a second of the retarders acts to convert linearly polarised light of wavelength $y\lambda$ (where $0.7<y<1.3$) to substantially circular polarised light, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal.

The wavelength λ is an operating wavelength of the reflective liquid crystal device and lies in the visible spectrum and is preferably in the range 400-700nm, more preferably 420-600nm, and more preferably still in the region 440-550nm. Most preferably λ is approximately 550nm.

Preferably, the retarder comprises a BTN liquid crystal providing a retardation of $n\lambda/4$.

According to a second aspect of the present invention there is provided a reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein a first of said retarders provides a retardation of substantially $m\lambda/2$ and a second of the retarders provides a retardation of substantially $n\lambda/4$ where m is an integer and n is an odd integer, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between a first state in which the retarder provides a retardation of substantially $m\lambda/2$ or $n\lambda/4$ and a second state in which the retardation is substantially zero.

According to a third aspect of the present invention there is provided a reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising at least three retarders, and a reflector, wherein at least one of said retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between first and second retardation states.

The wavelength λ is an operating wavelength of the reflective liquid crystal device and lies in the visible spectrum and is preferably in the range 400-700nm, more preferably 420-600nm, and more preferably still in the region 440-550nm. Most preferably λ is approximately 550nm.

Preferably, the retarder comprising a BTN liquid crystal providing a retardation in said first state of substantially $m\lambda/2$ or $n\lambda/4$ where m is an integer and n is an odd integer, and a retardation in said second state of substantially zero. The others of said retarders may provide a retardation of substantially $m\lambda/2$ or $n\lambda/4$.

"Optic axis" means slow optic axis.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention and in order to show how the same may be carried into effect reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a reflectance versus wavelength plot - maximum luminance attainable by the system;

Figure 2 is a reflectance versus wavelength plot - minimum luminance attainable by the system;

Figure 3 shows LC configurations for which LC behaves equivalently to an untwisted ¼ wave plate retarder ($\theta(\phi)$ = angle of the input director of LC with respect

to the incident linear polarisation direction, ϕ = twist of LC layer, $\Delta n.d/\lambda$ specifies the required $\Delta n.d/\lambda$ for which the LC device behaves like a ¼ wave plate retarder);

Figure 4 is a schematic representation of single polariser reflective configuration with a single retarder (BTN), LC configurations from table in Figure 3;

Figure 5 shows contrasts calculated as a function of $\Delta n.d/\lambda$ for the configurations described in Figure 4 and Figure 3 where the high twist state satisfies (ϕ+360°);

Figure 6 shows a luminous reflectance versus wavelength plot for the configuration providing the highest contrast described by configuration in Figure 4, low twist dark state;

Figure 7 shows a single retarder (BTN) in single polariser reflective configuration described in prior art by Xie & Kwok in Jpn. J. Appl. Phys, Vol37, part 1, No. 5a (1998), p 2572;

Figure 8 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 7, high twist dark state;

Figure 9 shows a two-retarder configuration described in prior art by Kim, Yu & Lee at IDRC Asia Display 98;

Figure 10 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 9, high twist dark state.

Figure 11 shows a two-retarder configuration in reflection described in Embodiment 1(a);

Figure 12 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 11, untwisted dark state;

Figure 13 shows a two-retarder configuration in reflection described in Embodiment 1(b);

Figure 14 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 13, untwisted dark state;

Figure 15 shows a two-retarder configuration in reflection described in Embodiment 2;

Figure 16 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 15, low twist dark state;

Figure 17 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 15; A retarder and LC thickness reduction of 30% provides the improved contrast;

Figure 18 shows a two-retarder configuration in reflection with an internal retarder described in Embodiment 3;

Figure 19 shows a luminous reflectance VS wavelength plot for the configuration shown in Figure 18,

untwisted dark state;

Figure 20(a) shows a two-retarder configuration in reflection described in Embodiment 4(a);

Figure 20(b) shows a two-retarder configuration in reflection described in Embodiment 4(b);

Figure 20(c) shows a two-retarder configuration in reflection described in Embodiment 4(c);

Figure 21 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 20(a);

Figure 22 shows a luminous reflectance VS wavelength plot for the configuration shown in Figure 20(b);

Figure 23 shows a luminous reflectance versus wavelength plot for the configuration shown in Figure 20(c);

Figure 24 shows a two-retarder configuration reflection described in Embodiment 5, θ_1 varied;

Figure 25 shows a luminous reflectance values of the dark state given by the low twist metastable state ϕ, as a function of θ_2 (from 0° to 360°);

Figure 26 shows a contrast plot obtained as a function of θ_1 (angle between polariser and half-wave retarder, see Figure 24) from 0° to 90°;

Figure 27 shows a luminous reflectance versus wavelength plot for $\theta_1=6°$, Embodiment 5;

Figure 28 shows a luminous reflectance versus wavelength plot for $\theta_1=84°$, Embodiment 5;

Figure 29 shows a two-retarder configuration in reflection described in Embodiment 6, d, θ and ϕ are varied;

Figure 30 shows a contrast plot as a function of $\Delta n.d/\lambda$, for each d the optimum θ and ϕ are found;

Figure 31 shows a Luminous reflectance versus wavelength plot for $\Delta n.d/\lambda=0.25$, d=2μm, Embodiment 6;

Figure 32 shows a three-retarder configuration in reflection described in Embodiment 7;

Figure 33 shows a luminous reflectance versus wavelength plot for configuration shown in Figure 32. Untwisted state provides the dark state;

Figure 34 shows a three-retarder configuration in reflection, described in Embodiment 8, d=2μm;

Figure 35 shows a luminous reflectance versus wavelength plot for configuration shown in Figure 34. Untwisted state provides the dark state;

Figure 36 shows a three-retarder configuration in reflection described in Embodiment 9, d=2.56μm;

Figure 37 shows a luminous reflectance versus wavelength plot for configuration shown in Figure 36; untwisted state provides the dark state, the bright state $\phi+180°$ twist state and $\phi\pm360°$ twist states are also plotted;

Figure 38 shows a three-retarder achromatic configuration in reflection described in Embodiment 10, d=2μm;

Figure 39 shows a luminous reflectance versus wavelength plot for configuration shown in Figure 38. High twist state provides the dark state;

Figure 40 shows a three-retarder achromatic configuration in reflection described in Embodiment 11; the LC orientation θ and twist ϕ are determined for different thickness LC layers. High twist state provides the dark state;

Figure 41 is a contrast plot shown as a function of $\Delta n.d/\lambda$, for each d the optimum θ and ϕ are found;

Figure 42 is a luminous reflectance versus wavelength plot for $\Delta n.d/\lambda=0.25$;

Figure 43 is a luminous reflectance versus wavelength plot for $\Delta n.d/\lambda=0.72$; and

Figure 44 is a luminous reflectance versus wavelength plot for $\Delta n.d/\lambda=0.536$.

BEST MODE FOR CARRYING OUT THE INVENTION

A Bistable Twisted Nematic (BTN) mode used in a reflection configuration requires one of its two metastable states, i.e. addressable states (ϕ & $\phi \pm 360°$), to provide a dark state and the other a bright state. A single retarder layer (i.e. BTN only) does not provide a good achromatic dark state when used with one polariser in reflection (demonstrated below). Configurations involving several retarder layers are required when seeking good achromatic dark states that switch to good bright states.

The likelihood of the undesired stable state $\phi \pm 180°$ nucleating into an addressed pixel means that its optical appearance (luminance, colour co-ordinates, etc.) may be of importance. It has been found that the stable state $\phi \pm 180°$ bears a closer resemblance optically to the high twist metastable state than to the low twist (or untwisted) metastable state, i.e. the reflection spectra of the ($\phi \pm 360°$) state is very similar to that of the ($\phi \pm 180°$) state.

The Embodiments to be described below provide the option of selecting which of the BTN metastable twist states will provide the dark state and which the bright states, for example in Embodiments 4 & 6 the low twist state gives the dark state and in Embodiment 11 the high twist state gives the dark state. It may be advantageous to select the high twist state to provide the "background" state for the display. By "background" state we refer to the state (dark or bright) that covers a greater percentage of the display over both space and time. For example, in an electronic book, black text would appear

on a white background to mimic printed paper, and as a result a large percentage of the display, say approximately 70%, would show white. So, for an electronic book the high twist state would be selected to provide the white state, i.e. the "background" state, so that if any of the undesired twist states ($\phi\pm180°$) did nucleate or remained in the inter-pixel (electrode) gaps (which may be the case if the gaps are very large and the LC is not switched within them) it would be less noticeable to the observer, with less of a detrimental effect on the contrast, than had the low twist ϕ state been selected to provide the "background" state.

Alternatively, a black mask can be used to mask-off the inter-pixel (electrode) gaps in the case where the LC within these gaps is not switched out of the undesired ($\phi\pm180°$) twist state by the application of a field during addressing.

Due to the similarity of the reflection spectra for the ($\phi\pm360°$) and the ($\phi\pm180°$) twist states (see Embodiment 9 below), those skilled in the art can apply this invention to the bistable device described by I. Dozov, M. Nobili and G. Durand, Appl. Phys. Lett. 70 (9), 3 March 1997.

In addition to the bright, high contrast requirements for reflection displays, the thickness of the LC layer has to be compatible with fabrication processes. A low birefringence (Δn) LC material provides a thicker LC layer, though it is also possible to increase the LC layer thickness by introducing a small amount of twist into the layer to compensate for the extra thickness

(this may modify the resulting optics). Alternatively, if the fabrication requires a thinner LC layer, a higher birefringence (Δn) LC material can be used.

Various BTN mode configurations were investigated by numerical modelling for their use in reflection displays. Being a reflective display the luminous reflectance of the bright state will depend on the light source utilised. In the examples given below, a CIE standard illuminant D-65 was used. Dispersion was included in all the modelled elements: 2μm thick aluminium reflector; 2.5μm polariser; 50μm retarders and LC layer. The low birefringence ($\Delta n \sim 0.0685$ at 20°C) liquid crystal MJ96538 (Merck Japan) was used in zero surface tilt configurations, with uniform twist profiles at zero applied field. (nb. Introducing a surface tilt may modify some of these results slightly).

The maximum contrast ratio ($CR = L_{MAX}/L_{MIN}$) attainable for a single polariser reflective system for the above-mentioned elements was calculated to be 169. The maximum luminance (L_{MAX}) results from the polariser-reflector configuration (no LC or retarders), and the minimum luminance (L_{MIN}) is obtained by adding a perfect (theoretical) quarter-wave retarder, i.e. quarter wave retarder at all wavelengths between the polariser and reflector, oriented at 45° to either the transmission or the absorption axis of the polariser. The luminous reflectance curves for this maximum (bright state) and minimum (dark state) luminances are shown in Figures 1 and 2. The dark state is very achromatic in behaviour while the bright state is governed both by the "shape" of the D65 light source and the polariser transmission

spectrum.

The embodiments of the invention to be described aim to obtain high contrast in reflection in various BTN configurations by means of achromatic dark states (dark over a wide range of wavelengths, preferably covering all the visible range) which switch to good bright states. Achromaticity of the dark and bright states is desired so that the display does not appear coloured.

The configurations constituting a single polariser reflective device consisting of a single (BTN) retarder and the configurations described in the prior art were modelled for comparative purposes. This was done using the elements as described previously, though suitably adjusted to match those described in the prior art.

The single polariser reflective configurations consisting of a single BTN retarder positioned between the reflector and the polariser require that the LC layer behave equivalently to an untwisted ¼ wave plate where the low twist provides the dark state. The LC configurations, i.e. the retardation $\Delta n.d/\lambda$ (Δn=birefringence, d=thickness, λ=wavelength), twist ϕ and angle $\theta(\phi)$ of the input director of LC with respect to the incident linear polarisation direction) that satisfy this requirement are listed in the table in Figure 3, covering a thickness range from 2μm to 6μm ($\Delta n.d/\lambda$ from 0.25 to 0.75 for LC MJ96538). The schematic representation of these configurations are provided in Figure 4; the BTN mode placed between the polariser and reflector at an orientation ($\theta(\phi)$) to the transmission

axis of the polariser. A dark state is obtained when the LC layer corresponds to a ¼-wave or ¾-wave retarder placed at 45° to the transmission axis of the polariser. The bright state corresponds to the high twist state ($\phi \pm 360°$). The contrast was calculated for each of the cases listed in table 3 where the high twist state corresponded to the (ϕ + 360°) and plotted as a function of $\Delta n.d/\lambda$, in Figure 5. Utilising the (ϕ - 360°) state for the bright state instead of the (ϕ + 360°) only changed the resulting contrast by a maximum of 1%, while for some cases it gave an identical contrast. The contrast does not decrease drastically until $\Delta n.d/\lambda>0.4$ (d >3.2µm). The highest contrast (CR=40) obtained was for a cell thickness of 2µm, untwisted LC layer, $\theta(\phi)=\pm45°$; though at a thickness of 2.8µm, $\phi=-63.6°$ and $\theta(\phi)=0°$ the contrast has only decreased to 39. Figure 6 shows the luminous reflectance as a function of wavelength for the dark and bright states of the highest contrast configuration (d=2µm, $\phi=0°$, $\theta(\phi)=\pm45°$). The dark states of all the configurations described in the table in Figure 3 are chromatic and become more so as the thickness of the LC layer increases (wavelength range over which there is a minimum reflectance reduces from 40nm to 25nm).

The configuration described by Xie & Kwok in Jpn. J. Appl. Phys, Vol37, part 1, No. 5a (1998), p 2572, is represented schematically in Figure 7. The high twist state provides the dark state; LC layer thickness 13.7µm, $\phi=-36°$ oriented parallel to the transmission axis of the polariser. The resulting luminous reflectance curves, shown in Figure 8, gave a very chromatic dark state leading to a contrast ratio of ~6. IDRC Asia Display 98 by Kim, Yu & Lee is represented in Figure 9; 2.9µm LC layer

thickness, $\phi=0°$ oriented at 45° to the transmission axis of the polariser. A 140nm retarder positioned between the polariser and BTN was either at 45° or 135° to the transmission axis of the polariser and depending on the retarder's orientation the resulting contrast was either ~13 or ~17. The resulting luminous reflectance curves are shown in Figure 10.

As can be seen, both the prior art and the single polariser reflective configurations with a single retarder (BTN) give low contrasts with chromatic dark states, compared to the maximum attainable contrast of 169.

The following configurations described in the embodiments are mostly examples of the LC layer acting as a switchable retarder located adjacent to the reflector. This set up aids fabrication purposes; i.e. no internal retarders are required in the device as they can be located externally. Two and three retarder configurations are investigated. In most of the embodiments discussed, any of the other retarder elements described in the configurations can be substituted by a LC layer so long as it adopts the correct retardation and orientation.

The configurations investigated obtain the dark state by converting linearly polarised light generated by the polariser into circularly polarised light. One of the BTN metastable states contributes to the conversion to circularly polarised light while the other metastable state doesn't. Upon reflection back through the system, a dark and a bright state are obtained. Alternatively, it is possible to convert the linearly polarised light generated by the polariser into elliptically polarised

light by altering the retarder properties, e.g. orientation and/or thickness, such that one of the BTN metastable twist states converts the elliptically polarised light to circular polarised light and the other metastable twist state converts elliptically polarised light to linear polarised light. Upon reflection back through the system a dark and a bright state are obtained.

Those skilled in the art will be able to vary the actual values from those in the embodiments and obtain acceptable performance. The tolerance x to these changes is of course configuration dependent, e.g. as seen in Figures 30 and 41. In all of the embodiments described below, either the transmission or the absorption axis of the polariser may be considered and give identical results.

It is noted that for each embodiment to be described, an equivalent can be obtained by changing the sign of each angle (i.e. by multiplying all the orientation angles of the retarders and LC as well as the LC twist by -1).

Embodiment 1

Half-wave ($\lambda/2$) retarder + quarter-wave ($\lambda/4$) LC - untwisted dark state ($\phi=0°$).

(a) Configuration shown in Figure 11: fixed half-wave ($\Delta n.d=270$) retarder at 15° to the transmission axis of the polariser followed by a quarter-wave ($\lambda/4$) LC layer at 75° to the transmission axis of the polariser. The LC layer is 2μm thick. A dark state which is more achromatic than that of a single retarder layer is

provided by the untwisted state, with a minimum reflectance over ~110nm wavelength range compared to the 40nm wavelength range obtained for the best single BTN layer in single polariser reflective configuration. The luminous reflectance plot is shown in Figure 12. The bright state is the same for both the +360° and -360° twisted state giving a contrast of 79.5.

In this case the fixed half-wave retarder rotates linearly polarised light of wavelength λ = 540nm whilst the quarter-wave LC layer converts light of wavelength $y \times \lambda$ (with y = 1) to circular polarised light. Less ideal, but reasonable, results can be obtained with y slightly different from 1. Maintaining λ = 540nm a contrast ratio of 29 is obtained for y = 0.9 whilst a contrast ratio of 31 is obtained for y = 1.1. It will be appreciated by those skilled in the art that the value of y can be optimised depending upon the embodiment and materials used.

(b) The half-wave retarder is placed at 22.5° to the transmission axis of the polariser and the LC layer at 90° to the transmission axis of the polariser, see Figure 13. The LC layer has a thickness of 2µm. The dark state is given by the untwisted state but both states are shown in Figure 14 to be quite chromatic. A contrast of 38 is obtained for such a configuration.

Embodiment 2

Half-wave ($\lambda/2$) retarder + quarter-wave ($\lambda/4$) LC - low twist ϕ provides dark state.

In this case, both BTN states have some degree of twist as a result of using a thicker LC layer (d=2.8µm).

The half-wave ($\lambda/2$) ($\Delta n.d=270$) retarder is at 15° to the transmission axis of the polariser with the LC layer oriented at 30° to the transmission axis of the polariser. A twist of $\phi=63.6°$ is incorporated to the LC layer and provides the dark state. The higher twist states ($\phi\pm360°$) provides the bright state of which the ($\phi-360°$)=-296.4° provides the better bright state. A diagram of this configuration is shown in Figure 15. A contrast of 31.6 is obtained. The luminous reflectance curves shown in Figure 16 suggest that the contrast would be higher were the curves shifted to the left. This can be achieved by reducing the thickness of the retarder and LC layer. For example, reducing both their thickness' by 30% resulted in a contrast of 66.5, over twice the previous contrast of 31.6. The luminous reflectance curves are shown in Figure 17.

Embodiment 3

Half-wave ($\lambda/2$) LC + internal quarter-wave ($\lambda/4$) retarder - untwisted dark state ($\phi=0°$).

This configuration is similar to Embodiment 1(a) except that the LC layer acts as the half-wave retarder ($\Delta n.d=270$) oriented at 15° to the transmission axis of the polariser. The LC layer thickness is 4μm. A fixed quarter-wave retarder ($\Delta n.d=132.5$) at 75° to the transmission axis of the polariser is located between the LC layer and the reflector, see Figure 18. The dark state corresponds to the untwisted state ($\phi=0°$) and the high twist state (±360°) to the bright state, the ±360° have the same luminous reflectance. The luminous reflectance curves are shown in Figure 19. A contrast of 64.6 is obtained.

The incorporation of an internal retarder inside a liquid crystal device is not an impractical technique, however it does increase the number of fabrication steps required.

The internal retarder can be fabricated using reactive mesogen (RM) materials, for example diacrylate RM257 (Merck Ltd, Poole). Reactive mesogens exhibit conventional liquid crystalline phases but undergo polymerisation under certain conditions, one of which being the exposure to ultraviolet light in a nitrogen atmosphere as the presence of oxygen inhibits the polymerisation reaction. Generally, a photoinitiator is required as a source of free radicals. Thus in the liquid crystalline phase the reactive mesogen can be aligned by an aligned alignment layer. The desired retardation can be obtained by tuning the spin conditions (layer thickness), the concentration of the reactive mesogen solution, the temperature at curing or a combination of all these.

The basic structure of the device can for example consist of a patterned aluminium (Al) reflector that doubles as the electrode, an aligned alignment layer on the reflector which aligns a reactive mesogen layer with the desired orientation and retardation. A second alignment layer can be placed on to the internal retarder. The device can be formed by combining this reflector-substrate with a counter substrate containing a patterned transparent patterned electrode, for example Indium tin oxide layer (ITO), coated by an (aligned) alignment layer to align the BTN LC layer. Additionally, a (patterned)

transparent electrode may be placed on to the internal retarder (between the internal retarder and the alignment layer) in order to reduce the voltage drop that may occur across the internal retarder when using the reflector as the electrode.

Embodiment 4

Specific wavelength ($\lambda/2$) retarder + twisted LC configurations - low twist provides the dark state ϕ.

Three such solutions were investigated and are shown schematically in Figure 20, labelled (a) to (c). The LC layer is twisted through ϕ to give the dark state and the bright state corresponds to the higher twisted case ($\phi\pm360°$). The optimum bright state was obtained for the (ϕ-360°) twist state, providing reasonable contrasts:

(a) An untwisted fixed ($\Delta n.d$=185nm) retarder and ($\Delta n.d$=174nm, d=2.54μm) LC layer, are both orientated at 15° to the transmission axis of the polariser. The LC has a twist (ϕ) of 85.5°. This configuration gives a contrast of 87 and the luminous reflectance curves are plotted in Figure 21.

(b) The untwisted fixed (Δnd=221nm) retarder is orientated at 15° to the transmission axis of the polariser and (Δnd=152nm, d=2.22μm) LC layer is orientated at 32.5° to the transmission axis of the polariser with an internal twist (ϕ) of 63.6°. The luminous ~~reflectances~~ reflectance curves are plotted in Figure 22 and a contrast of 81 was obtained.

(c) The untwisted fixed (Δnd=208nm) retarder is orientated at 14° to the transmission axis of the polariser

and (Δnd=152nm, d=2.22µm) LC layer is orientated at 29° to the transmission axis of the polariser with an internal twist (ϕ) of 67°. The luminous reflectance curves are plotted in Figure 23 and a high contrasts of 99 was obtained.

Embodiment 5

Configurations where the angle (θ_2) between the polariser and LC layer satisfies $\theta_2=2\theta_1$ where θ_1 is the angle between the polariser and half-wave retarder - low twist state (ϕ) provides the dark state.

These configurations are illustrated in Figure 24: half-wave retarder ($\Delta n.d$=270) placed between the LC layer and polariser at an angle of θ_1 to the transmission axis of the polariser and the LC layer is at θ_2 to the transmission axis of the polariser where $\theta_2=2\theta_1$ (since the half-wave retarder rotates linear polarisation by $2\theta_1$); varying θ_1 from 0° to 180° (i.e. θ_2 from 0° to 360°), and calculating the luminous reflectance curves for the low twist (dark) state as a function of θ_2 for a LC layer, thickness of 2.8µm and low twist state of $\phi=\pm63.6°$ selected from the table in Figure 3. This LC layer configuration constitutes just one example chosen from the table in Figure 3 and any thickness with its corresponding twist can be chosen and subjected to a similar procedure. A negative ϕ twist requires the values of θ_1 and all corresponding angles to be reversed in sign. The luminous reflectance values for the low twist state are plotted as a function of θ_2 in Figure 25. These results indicate that a positive low LC layer twist provides a lower luminance (better dark state) over the 0° to 180° range for θ_2 than an equivalent negative LC layer twist.

The resulting contrasts were calculated as a function of θ_1 and shown in Figure 26. Two regions were found to give good contrasts, $\theta_1 \approx 6°$ & $84°$, with respective contrasts of 50.5 and 59. The luminous reflectance curves for $\theta_1=6°$ are shown in Figure 27, the dark state has a high luminous reflectance at low wavelengths which lowers the overall contrast, even though at higher wavelengths the dark state looks very achromatic. An improved dark state at low wavelengths can be obtained by shifting the curves to the left by reducing the retarder and LC layer thickness as demonstrated in Embodiment 2. The dark state at $\theta_1=84°$ has a lower leakage of light at short wavelengths (λ<450nm) than the dark state at $\theta_1=6°$, see the luminous reflectance curves in Figure 28, resulting in an overall higher contrast even though the wavelength range over which both these dark states have a minimum transmission of light is the same.

This exercise can be repeated for different retarder and LC layer thickness' (and hence different LC layer twist) to try and improve the contrast and/or increase the LC layer' thickness.

Embodiment 6

Fixed half-wave ($\lambda/2$) retarder + variable thickness LC layer - low twist (ϕ) provides dark state.

This arrangement is shown in Figure 29, a half-wave retarder ($\Delta n.d=270$) at 15° to the transmission axis of the polariser. The LC layer is placed between the retarder and reflector and the low twist state provides the dark state. The thickness of the LC layer

is selected from the table of LC configurations in Figure 3 (between $\Delta n.d/\lambda=0.25$ & 0.75) and for each thickness the configuration (orientation θ and twist ϕ) giving the best dark state was determined via locating the minima on a 3-D surface plot. The contrast as a function of LC layer thickness was obtained. These contrasts are plotted as a function of $\Delta n.d/\lambda$ (birefringence Δn, thickness d, wavelength λ) in Figure 30. As $\Delta n.d/\lambda$ increases the contrast rapidly decreases. A maximum contrast of 89 was obtained, corresponding to a $\Delta nd/\lambda= 0.25$, d=2μm, $\theta=81°$, $\phi=-11°$. The corresponding luminous reflectance curves for $\phi=-11°$ and $\phi=349°$ twist states are given in Figure 31. The (ϕ+360°) high twist state gave a higher luminance than the (ϕ-360°) high twist state.

Further improvements are possible by varying the retardation (thickness) of the fixed half-wave retarder and repeating this exercise.

Embodiment 7

Two half-wave ($\lambda/2$) retarders + ($3\lambda/4$) LC - untwisted dark state $\phi=0°$.

Two half-wave retarders ($\Delta n.d=270$) placed at 15° and -15° to the transmission axis of the polariser with a 6μm LC layer at 75°, as shown in Figure 32. The untwisted state corresponds to the dark state and the high twist state gives the bright state. The resulting dark and bright states are not very achromatic, see reflectance curves plotted in Figure 33, leading to a low contrast of 20. Dark state has a short 500-550nm wavelength range. The luminous reflectance curves (e.g. 0° and -360° twist states) are very chromatic which may be usable as a two

colour display (achromatic dark state and coloured bright state).

Embodiment 7 can be seen as belonging to a more general case:
$(\lambda/2)$ @ ~15° + $[(\lambda/4)+x]$ @ ~-15° + $[(\lambda/2)+x]$ @ ~75° where x lies between 0 & $\lambda/4$.

Embodiment 8
Two half-wave $(\lambda/2)$ retarders + $(\lambda/4)$ LC - untwisted dark state $\phi=0°$.

The two half-wave retarders ($\Delta n.d=270$) are at 6.9° and 34.5° to the transmission axis of the polariser, as shown in Figure 34. An untwisted, 2μm LC layer, at 100° to the transmission axis of the polariser, provides a good achromatic dark state (minimum reflectance over ~180nm wide wavelength range), with the exception that at very low wavelengths the dark state becomes poor, see Figure 35. The high twist (±360°) state in turn gives a good bright state (though chromatic in behaviour) which leads to a contrast of 89. The dark state may be improved (possibly increasing the contrast) by decreasing the thickness of the retarders and LC layer.

Additionally, increasing the thickness of the LC layer and determining for that thickness the optimum (θ orientation and ϕ twist of LC layer) configuration as described in Embodiment 6, other high contrasts may be found. It could also be possible to increase the thickness of the LC layer by using the LC as one of the $(\lambda/2)$ elements instead of the $(\lambda/4)$ element, though this would require an internal retarder which could be

fabricated by a reactive mesogen layer as described in Embodiment 3.

Embodiment 9
A (23λ/72) and (λ/2) retarder + LC (23λ/72) - untwisted dark state ϕ=0°.

A 23λ/72 (@550nm) retarder placed at 14.25° to the transmission axis of the polariser followed by a half-wave (Δn.d=270) retarder at 84.5°. The LC is oriented at 14.25° and has a retardation of ~23λ/72 (d=2.56μm). Figure 36 gives a schematic representation of this configuration. The dark state is given by the untwisted state ϕ=0°. The bright state is obtained by the high twisted (±360°) state, though the undesired ±180° twist state gave a higher luminance than the ±360° twist state, as can be seen in Figure 37. A contrast of 55 is obtained.

The thickness of the LC layer could be increased by using the LC as the (λ/2) element instead of the (23λ/72) element, though this again would require an internal retarder.

Embodiment 10
Achromatic configuration + LC: (λ/2) retarder + (λ/4) retarder + (λ/4) LC layer.

This configuration is different to all the previous configurations discussed because the fixed retarder(s) provide the dark state and the LC is used to switch their effect on and off. Therefore, the high twist state gives the dark state and the low twist state gives the bright state.

The half-wave ($\Delta n.d=270$) retarder is at 15° to the transmission axis of the polariser and the quarter-wave ($\Delta n.d=132.5$) retarder and LC layer are both at 75°, as shown in Figure 38. A 2μm thick LC layer was used and this gave a contrast of 96 with a good dark state that is reasonably achromatic, except at low wavelengths. Luminous reflectance curves are shown in Figure 39, it can be observed that the high twist (±360°) states gave very similar dark states.

Embodiment 11
Achromatic configuration + LC (varying the LC layer thickness) - high twist dark state.

This configuration utilises the same half-wave/quarter-wave retarder configuration used in Embodiment 10: the LC switches the achromatic quarter-wave configuration on and off. The LC configuration (θ and ϕ) which gave the best dark state for a given LC layer thickness was found. Repeating over a range of LC layer thickness' and therefore $\Delta nd/\lambda$ as done in Embodiment 6. The bright state was given by the corresponding low twist state. The general configuration is represented in Figure 40. The contrasts determined were plotted as a function of $\Delta nd/\lambda$ in Figure 41. Once again, two contrast maxima are found. The highest occurs at $\Delta nd/\lambda=0.25$ (d=2μm, $\theta=-70°$, $\phi=-15°$) and gives a contrast of 133. Its luminous reflectance curves are plotted in Figure 42. As can be seen, a very good dark state (very achromatic) and a very reasonable bright state are obtained, though both are poor at low wavelengths. The second maxima occurs at $\Delta nd/\lambda\sim0.72$ (d=5.781μm, $\theta=3°$, $\phi=-24°$), contrast of 106.

The dark state is reasonably good but the bright state is very chromatic, see its' reflectance curves in Figure 43.

An example of one of the poorer contrasts (CR=23) obtained (thickness of 4.3μm, θ=0°, ϕ=-15°) is also included. Its reflectance curves, Figure 44, show a reasonable dark state with a very poor bright state.

INDUSTRIAL APPLICABILITY

According to the invention, high contrast is obtained in reflection in various BTN configurations by means of achromatic dark states (dark over a wide range of wavelengths, preferably covering all the visible range) which switch to good bright states.

CLAIMS

1. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein, in at least one state of the device, a first of said retarders acts to rotate linearly polarised light of wavelength λ and a second of the retarders acts to convert linearly polarised light of wavelength $y\lambda$ (where $0.7<y<1.3$) to substantially circular polarised light, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal.

2. A device according to claim 1, wherein $0.8<y<1.3$.

3. A device according to claim 1, wherein the BTN is switchable between a first state in which it rotates linearly polarised light and a second state in which it does not rotate linearly polarised light.

4. A device according to claim 1, wherein the BTN is switchable between a first state in which it substantially converts linearly polarised light to circularly polarised light and a second state in which it does not convert linearly polarised light to circularly polarised light.

5. A device according to any one of claims 1 to 4, wherein the retarder adjacent to the polariser is a fixed retarder with an optic axis at an angle θ_1 to either the transmission or absorption axis of the polariser, and the retarder adjacent to the reflector is a BTN which in the low twist state, ϕ, has the input director (LC director at cell surface adjacent to retarder) at an angle $\theta_2 = 2\theta_1+\theta\ (\phi)\ +x$.

6. A device according to claim 5, wherein $x < 5°$.

7. A device according to claim 5 or 6, wherein θ_1 is substantially 15° and the low twist state is substantially $\phi = 0°$.

8. A device according to claims 5 or 6, wherein $5° < \theta_1 < 25°$ and the low twist state is substantially $\phi = 63.6°$.

9. A device according to claim 5 or 6, wherein $\theta_1 = 15°$ and the low twist state is substantially $\phi = 63.6°$.

10. A device according to claim 8, wherein $\theta_1 = 6°$ and the low twist state is substantially $\phi = 63.6°$.

11. A device according to claims 4 or 5, wherein $5° < 90° - \theta_1 < 25°$ and the low twist state is substantially $\phi = 63.6°$.

12. A device according to claim 11, wherein $\theta_1 = 84°$ and the low twist state is substantially $\phi = 63.6°$.

13. A device according to claim 5, wherein θ_1 and θ_2 are both substantially 15° and the low twist state is substantially $\phi = 85°$.

14. A device according to claim 1 or 2, wherein the retarder adjacent to the polariser is a BTN which in the low twist state has $\phi = 0°$ and optic axis at an angle α to either the transmission or absorption axis of the polariser and the retarder adjacent the reflector is a fixed retarder with optic axis at an angle $2\alpha + 45° + x$.

15. A device according to claim 14, wherein $x < 5°$, preferably $0°$.

16. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising two retarders, and a reflector, wherein a first of said retarders provides a retardation of substantially $m\lambda/2$ and a second of the retarders provides a retardation of substantially $n\lambda/4$ where m is an integer and n is an odd integer, and wherein at least one of the said first and second retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between a first state in which the retarder provides a retardation of substantially $m\lambda/2$ or $n\lambda/4$ and a second state in which the retardation is substantially zero.

17. A device according to claim 16, wherein the wavelength λ is an operating wavelength of the reflective liquid crystal device and is in the range 400-700nm.

18. A device according to claim 17, wherein the wavelength λ is in the range 420-600nm.

19. A device according to claim 18, wherein the wavelength λ is in the range 440-550nm.

20. A device according to any of claims 16 to 19, wherein the retarder comprising a BTN liquid crystal provides a retardation of $n\lambda/4$.

21. A reflective liquid crystal device comprising in sequence a linear polariser, a retarder arrangement comprising at least three retarders, and a reflector,

wherein at least one of said retarders comprises a Bistable Twisted Nematic (BTN) liquid crystal and is switchable between first and second retardation states.

22. A device according to claim 21, wherein the retarder adjacent to the reflector acts to convert linearly polarised light of wavelength $y\lambda$ ($0.7<y<1.3$) to substantially circular polarised light, and the two other retarders act to rotate linearly polarised light of wavelength λ.

23. A device according to claim 22, wherein the retarder adjacent the polariser is at angle α to the axis of the polariser, the next retarder is at angle β to the axis of the polariser and the retarder adjacent the reflector is a BTN which in the low twist state, ϕ, has the input director (LC director at cell surface adjacent to retarder) at an angle $2(\beta-\alpha)+\theta(\phi)+x$ to the axis of the polariser.

24. A device according to claim 23, wherein $x < 5°$, preferably $0°$.

25. A device according to claim 24 in which $\alpha = 6.9°$ and $\beta = 34.5°$.

26. A device according to claim 21, wherein the retarder adjacent to the polariser acts to rotate linearly polarised light of wavelength λ, the middle retarder acts to convert linearly polarised light of wavelength $y\lambda$ ($0.7<y<1.3$) to substantially circular polarised light, and the retarder adjacent to the reflector is a BTN device.

27. A device according to claim 26, wherein the retarder adjacent to the polariser has optic axis at α to the axis of the polariser, the middle retarder has optic axis at $2\alpha+45°$ to the axis of the polariser.

28. A device according to claim 27, wherein $\alpha=15°$ and the BTN has a low twist state of 0° orientated at 75° to the transmission axis of the polariser.

29. A device according to claims 21, wherein said at least one retarder provides a retardation in said first state of substantially $m\lambda/2$ or $n\lambda/4$ where m is an integer and n is an odd integer, and a retardation in said second state of substantially zero.

30. A device according to claims 22 to 29, wherein the wavelength λ is an operating wavelength of the reflective liquid crystal device and is in the range 400-700nm.

31. A device according to claim 30, wherein the wavelength λ is in the range 440-550nm.

32. A device according to any of the preceding claims in which the BTN switches between a state ϕ and $(\phi\pm360°)$.

33. A device according to any of the preceding claims in which the BTN switches between a state ϕ and $(\phi\pm180°)$.

FIG. 1

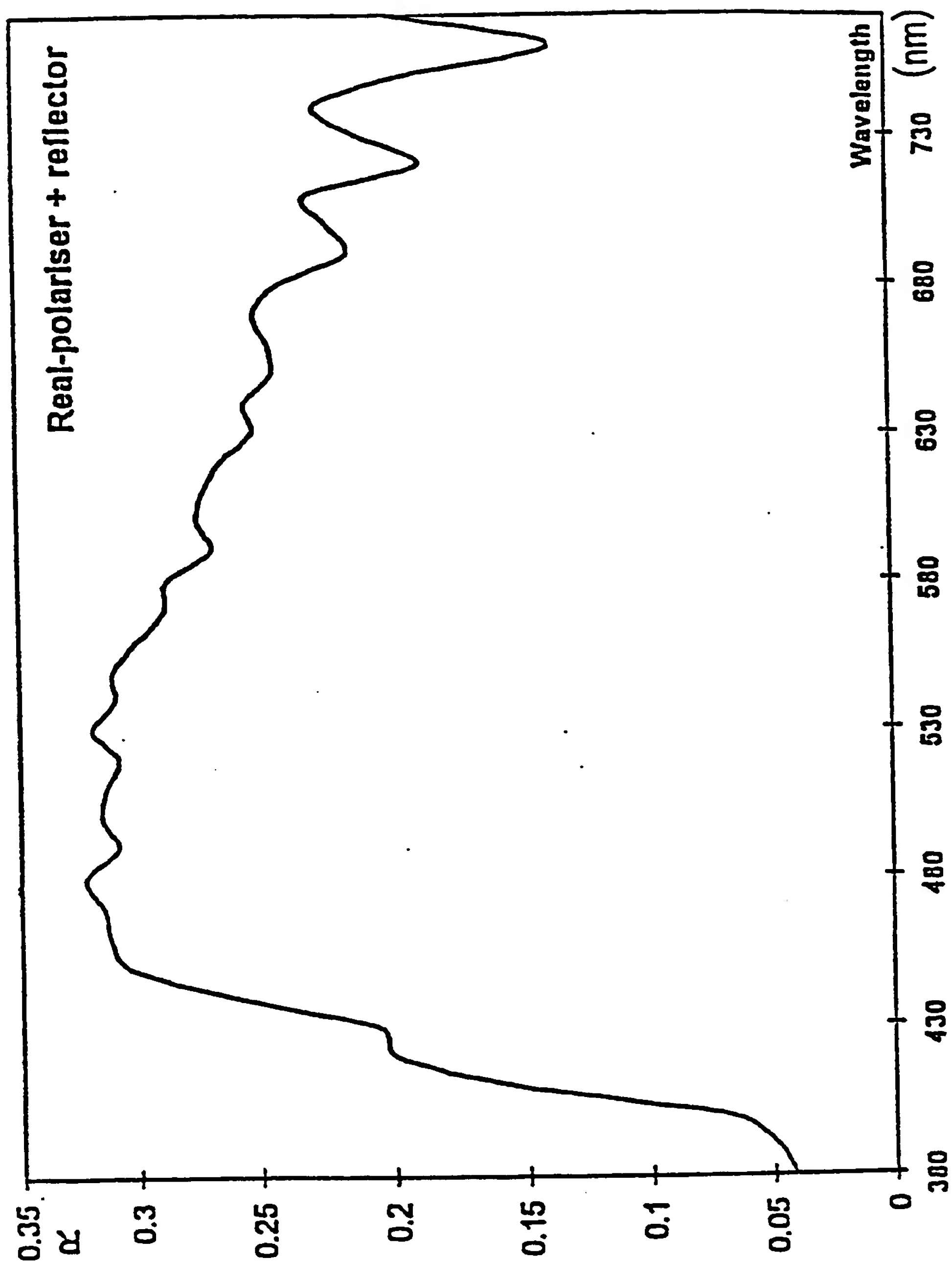

Real-polariser + reflector
α
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength (nm)

FIG. 2

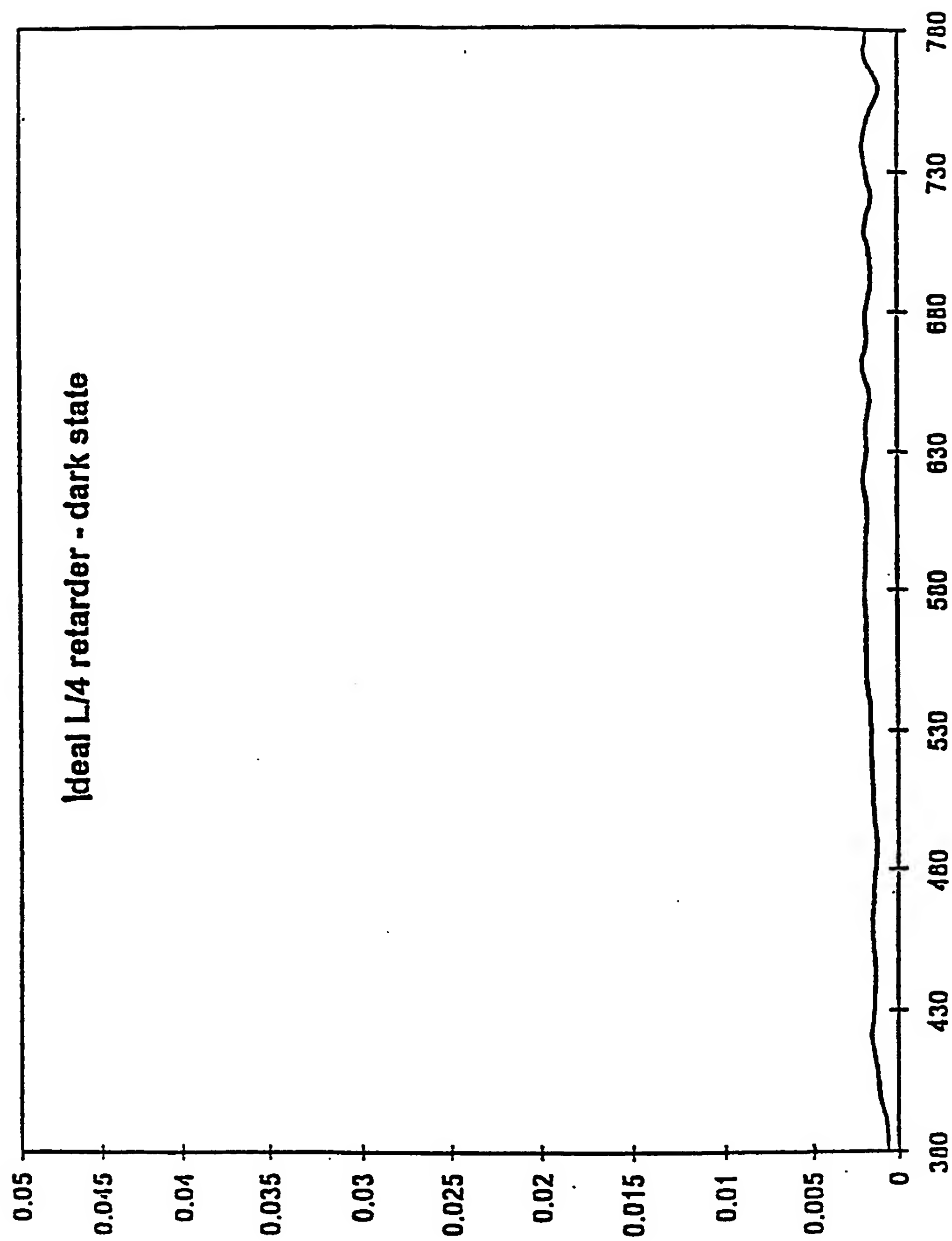

Ideal L/4 retarder - dark state
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
300
430
480
530
580
630
680
730
780

FIG.3

	Twist of LC layer ϕ (degrees)	Input director of LC $\theta(\phi)$ (degrees)	$\Delta nd/\lambda$ (λ=550nm)	Thickness of LC d (μm)
1	0	-45	.25	2.007
2	-11.4	-37.76	.252	2.023
3	-23.4	-30	.26	2.088
4	-36.7	-21.1	.275	2.208
5	-50.6	-11.1	.304	2.441
6	-63.6	0	.354	2.842
7	-70.1	8	.405	3.252
8	-72.5	15.2	.467	3.75
9	-69.9	21.78	.536	4.304
10	-65.5	25.66	.582	4.673
11	-58.1	29.6	.63	5.058
12	-50	32.7	.667	5.355
13	-38.4	36.2	.704	5.653
14	-25.1	39.5	.731	5.869
15	-12.1	42.4	.746	5.99
16	0	45	.75	6.022

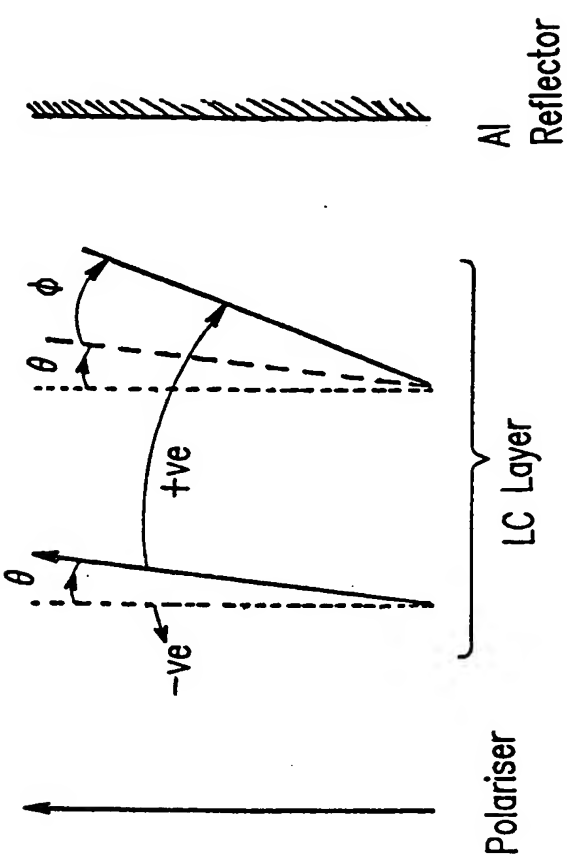


FIG. 4

FIG.5

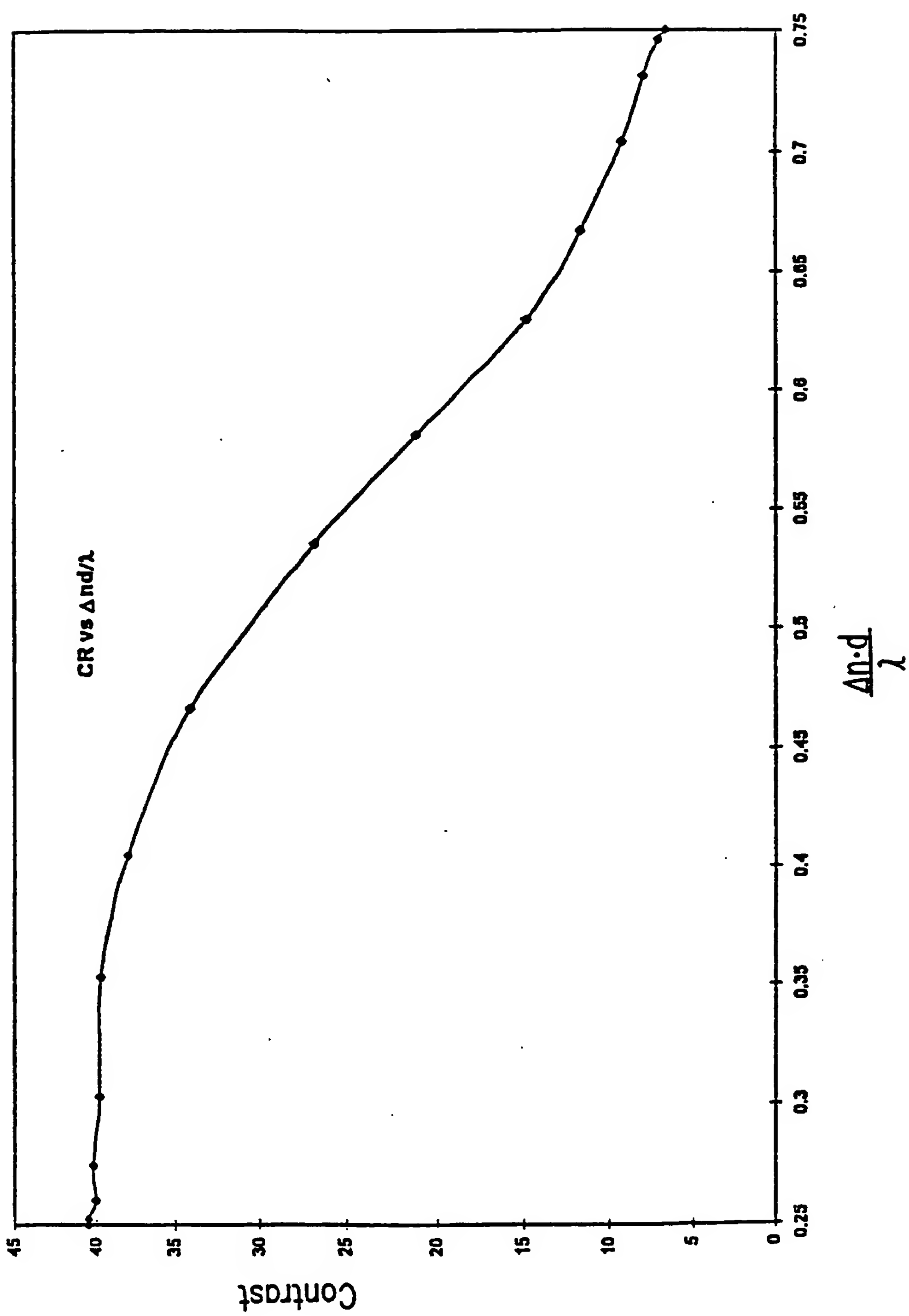
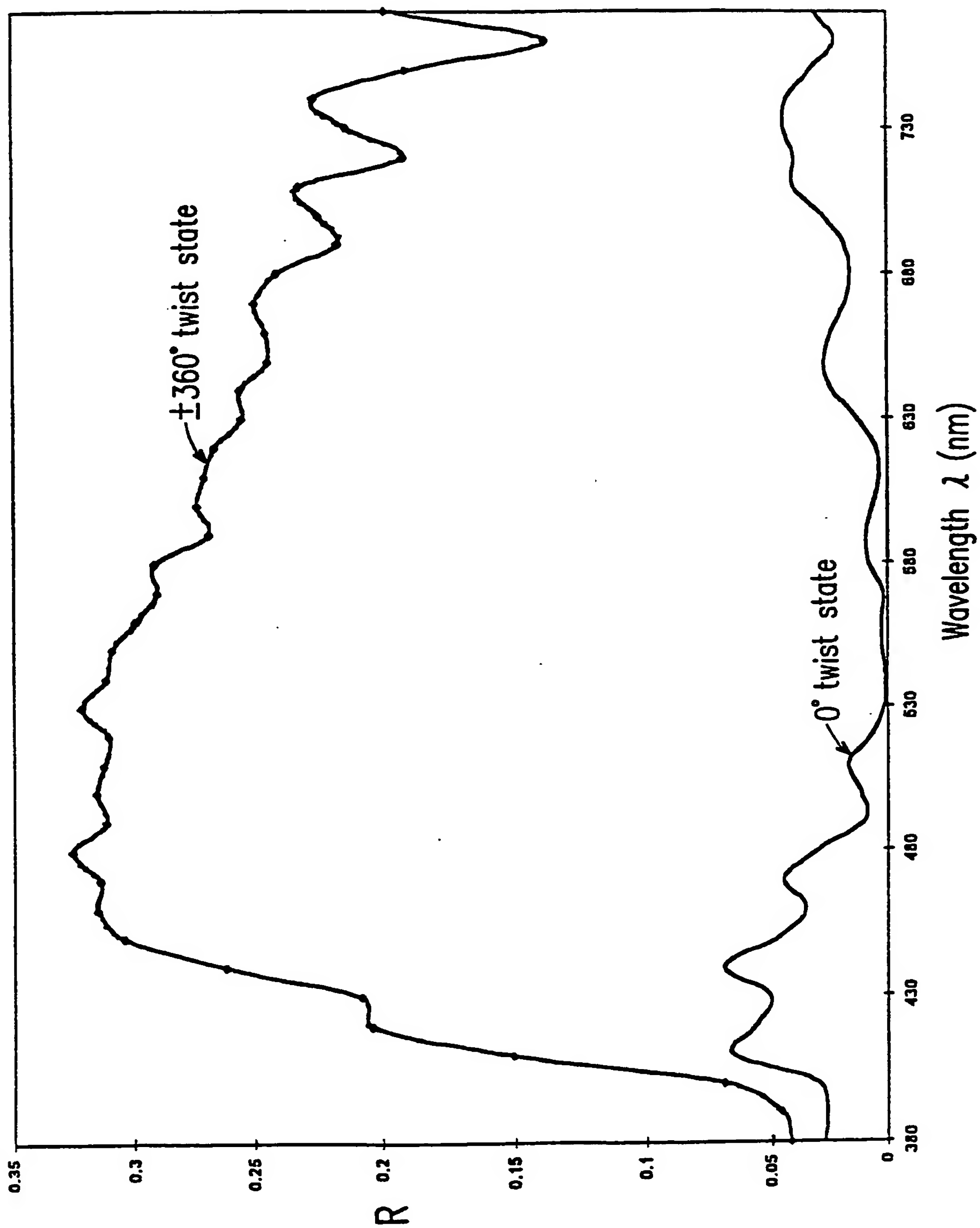

CR vs Δnd/λ
Contrast
45
40
35
30
25
20
15
10
5
0
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
$\frac{\Delta n \cdot d}{\lambda}$

FIG.6


±360° twist state
0° twist state
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)

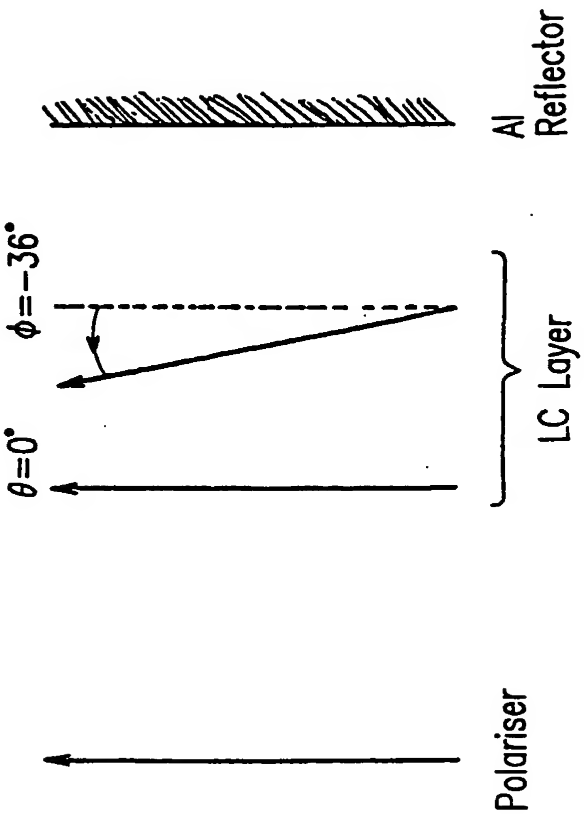
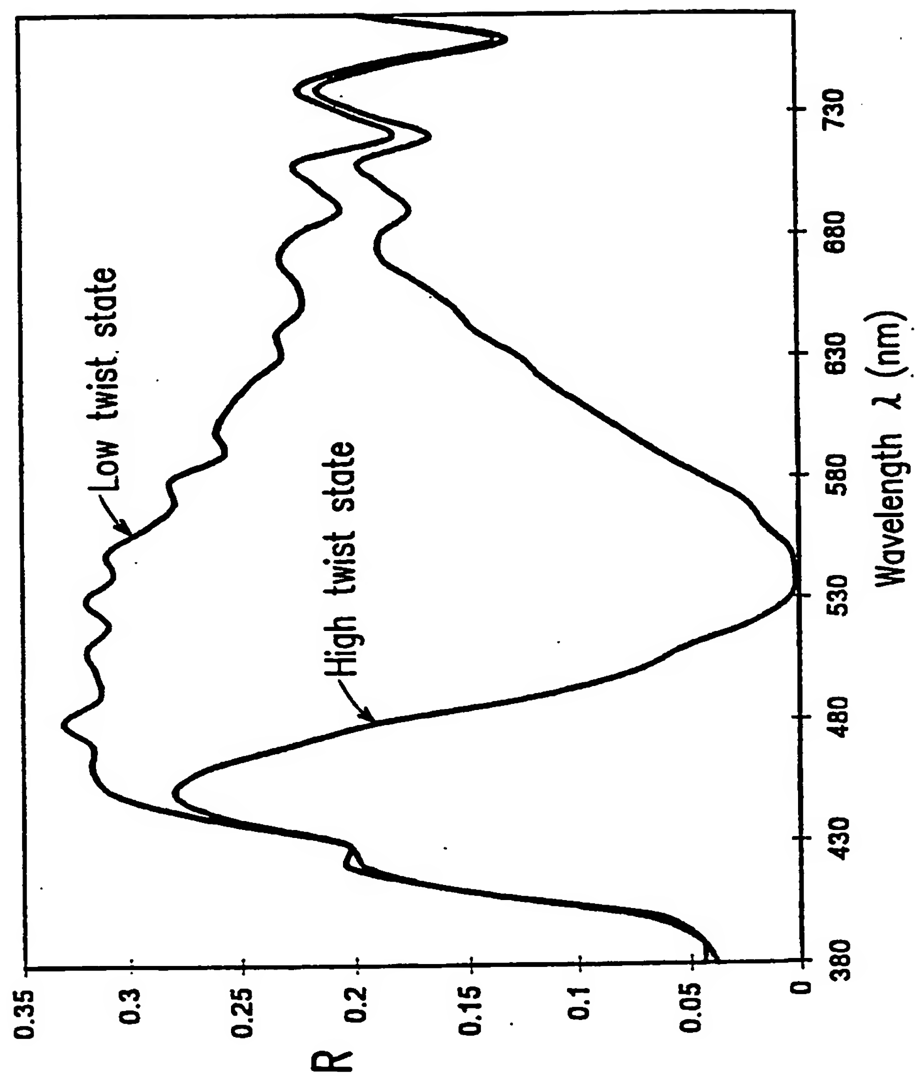


FIG. 7

FIG.8


Low twist state
High twist state
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)

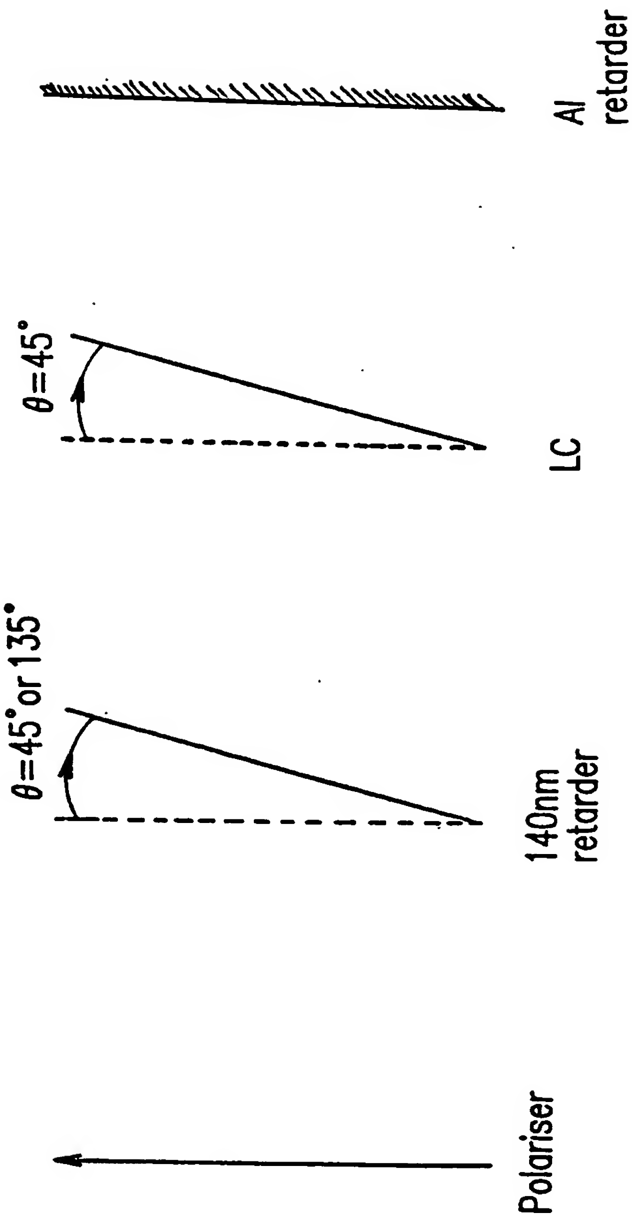
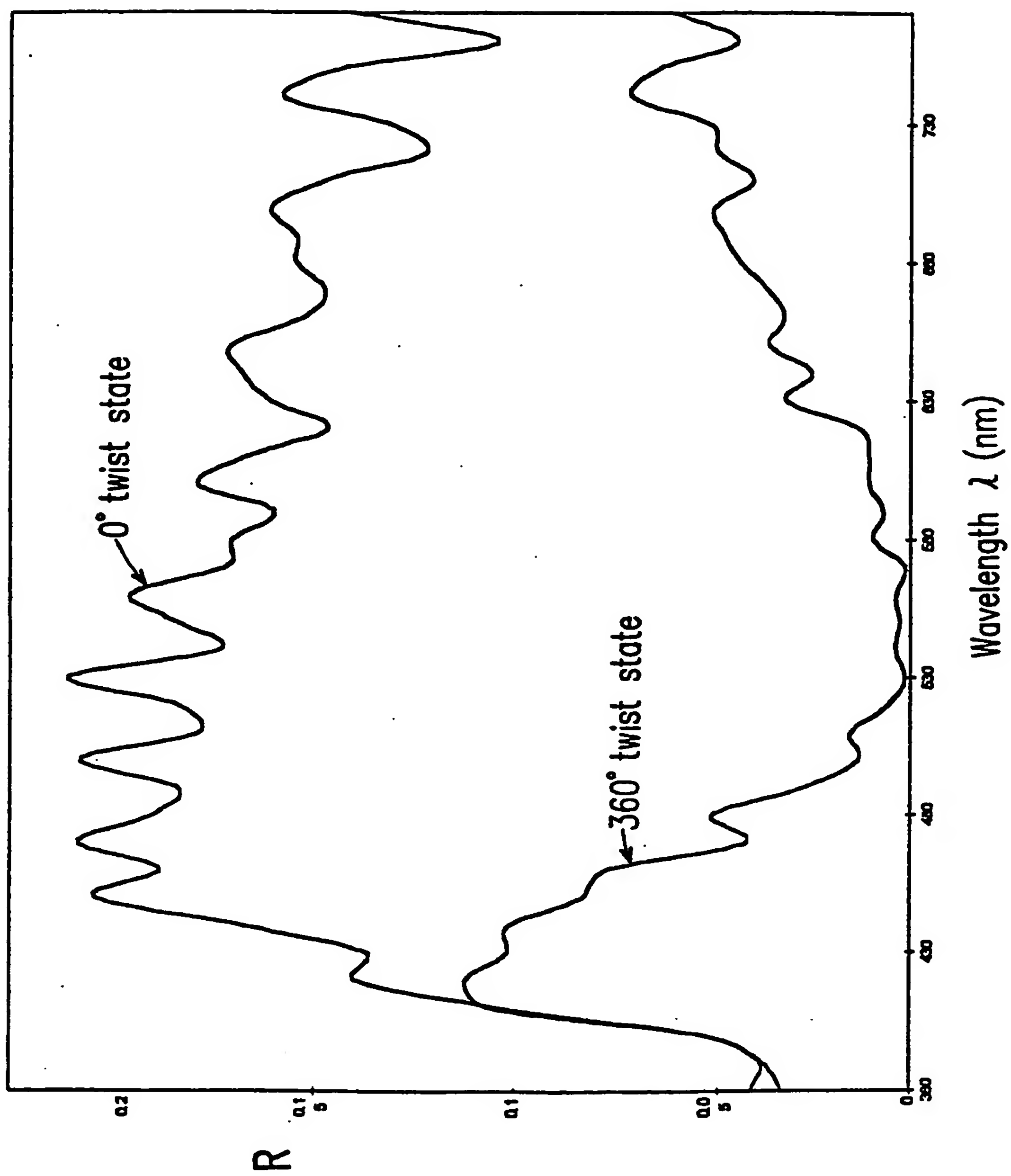


FIG.9

FIG. 10


0° twist state
360° twist state
R
Wavelength λ (nm)
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730

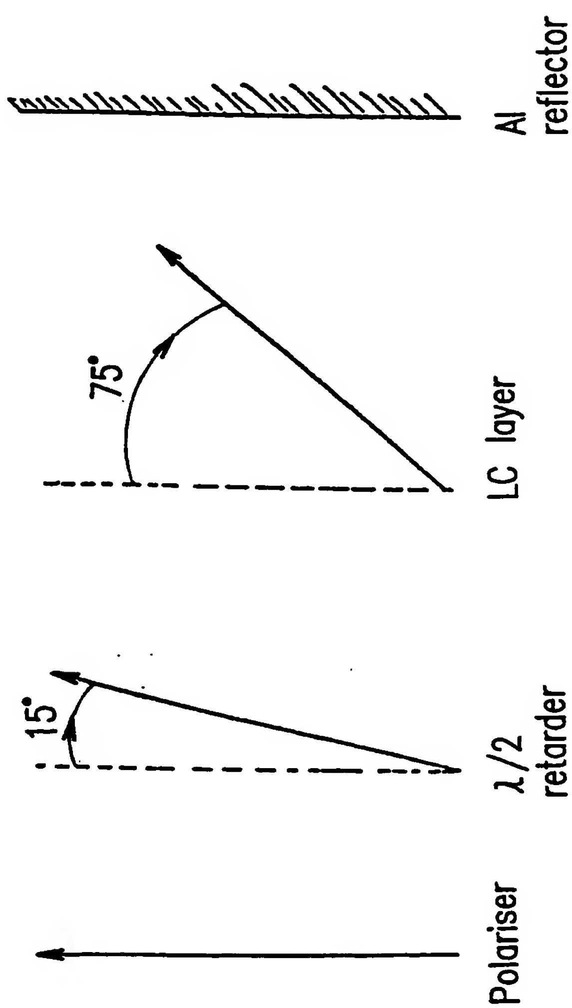


FIG. 11

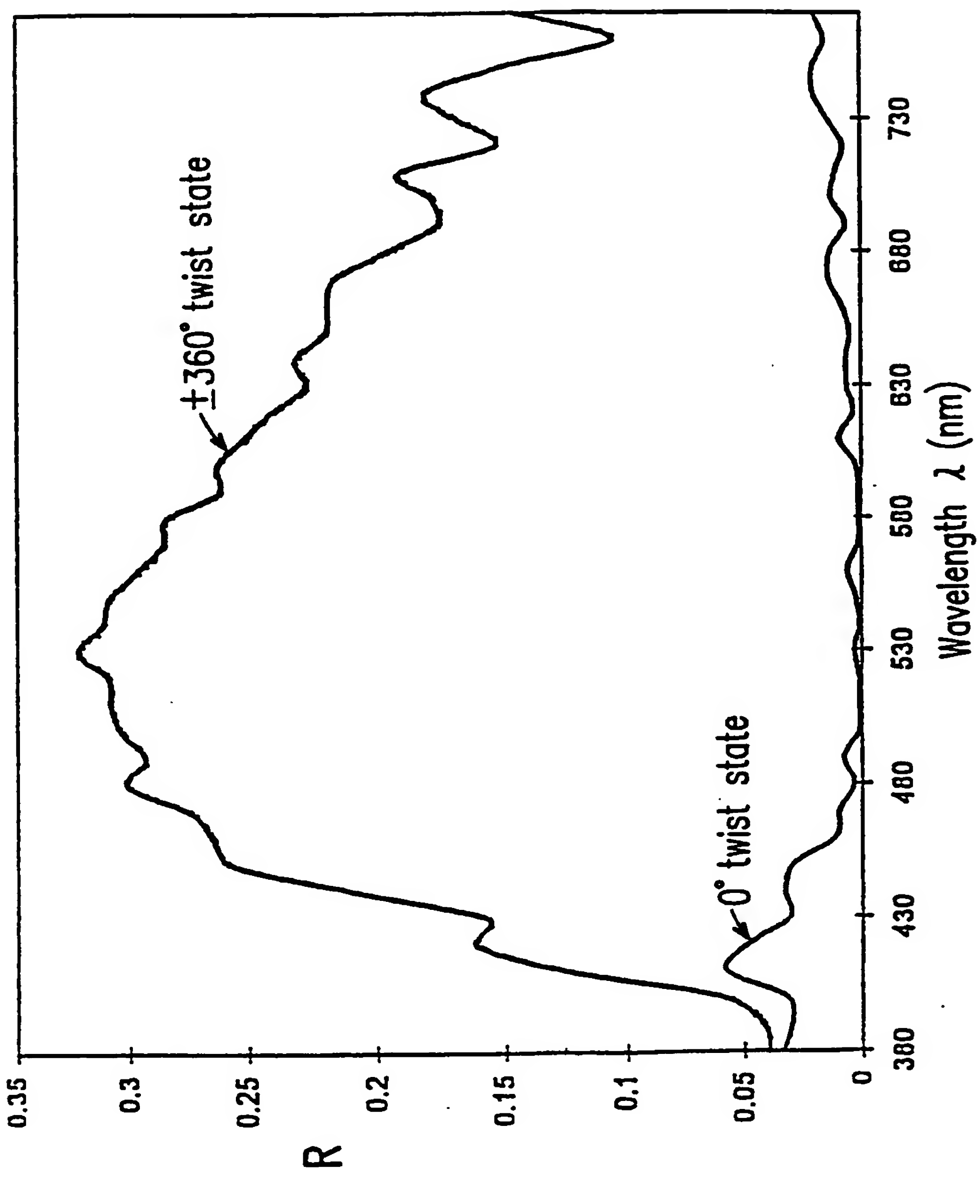

±360° twist state
0° twist state
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)

FIG. 12

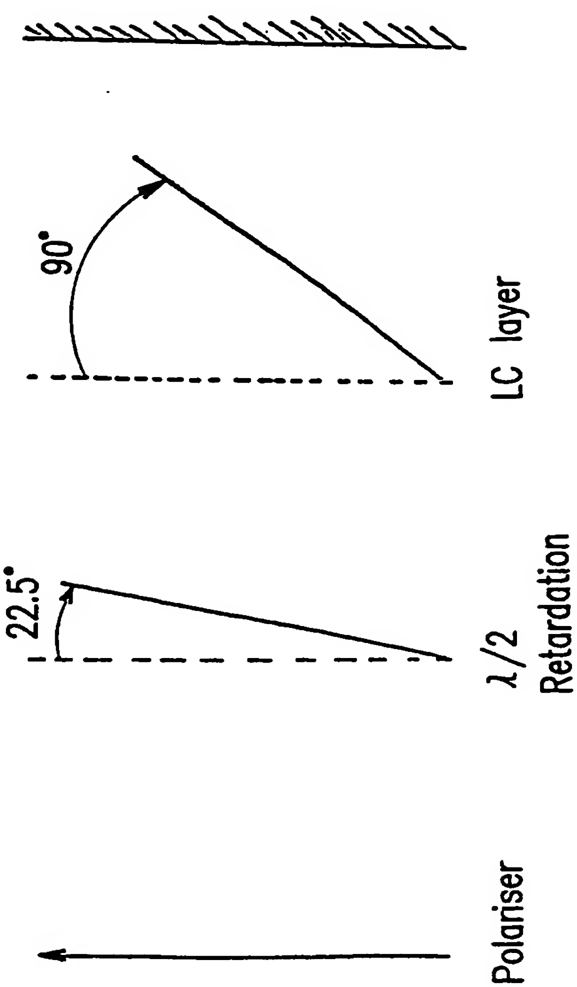
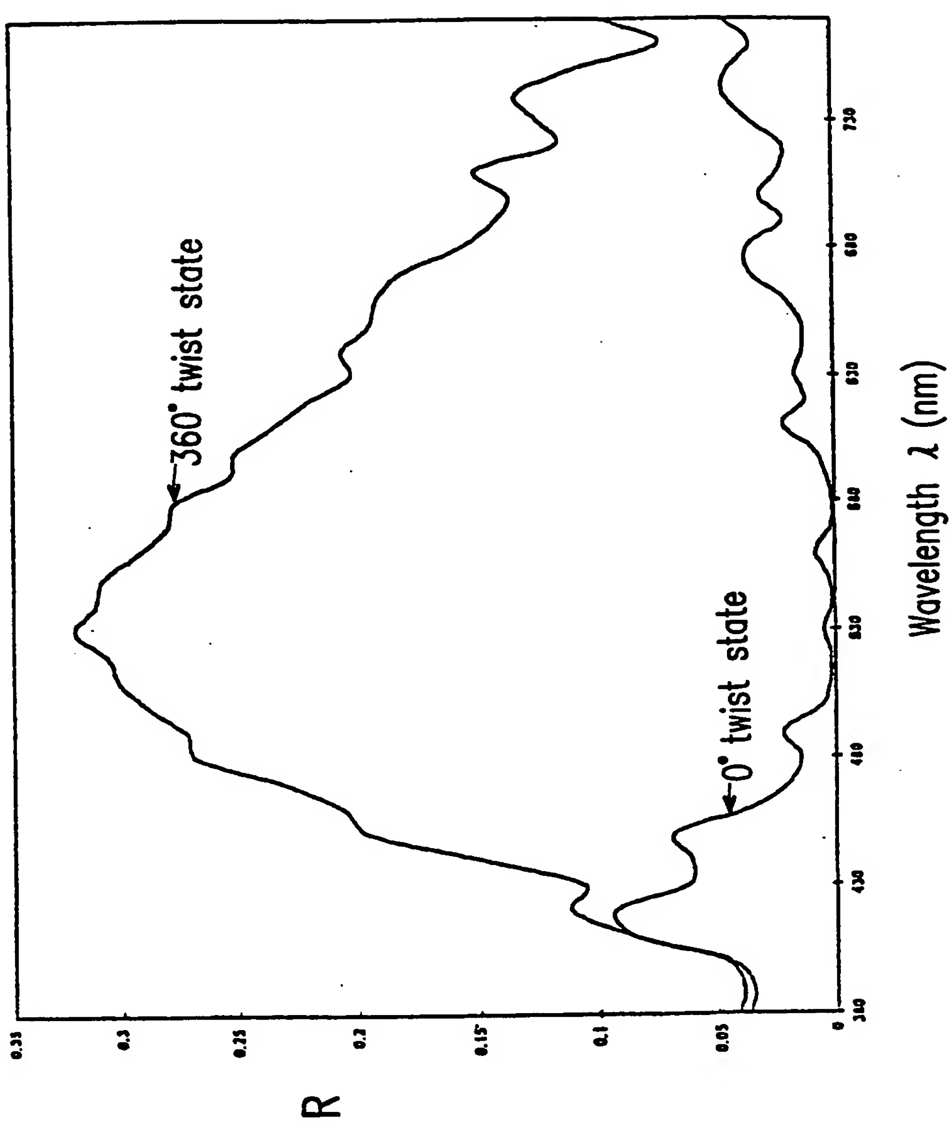


FIG. 13

FIG. 14



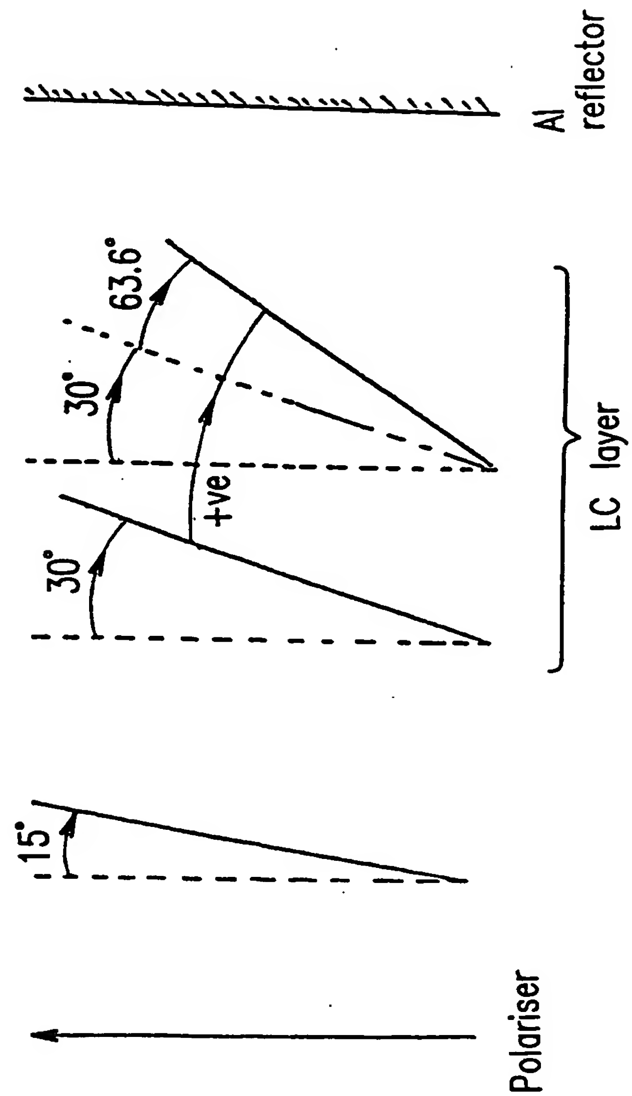


FIG. 15

FIG.16

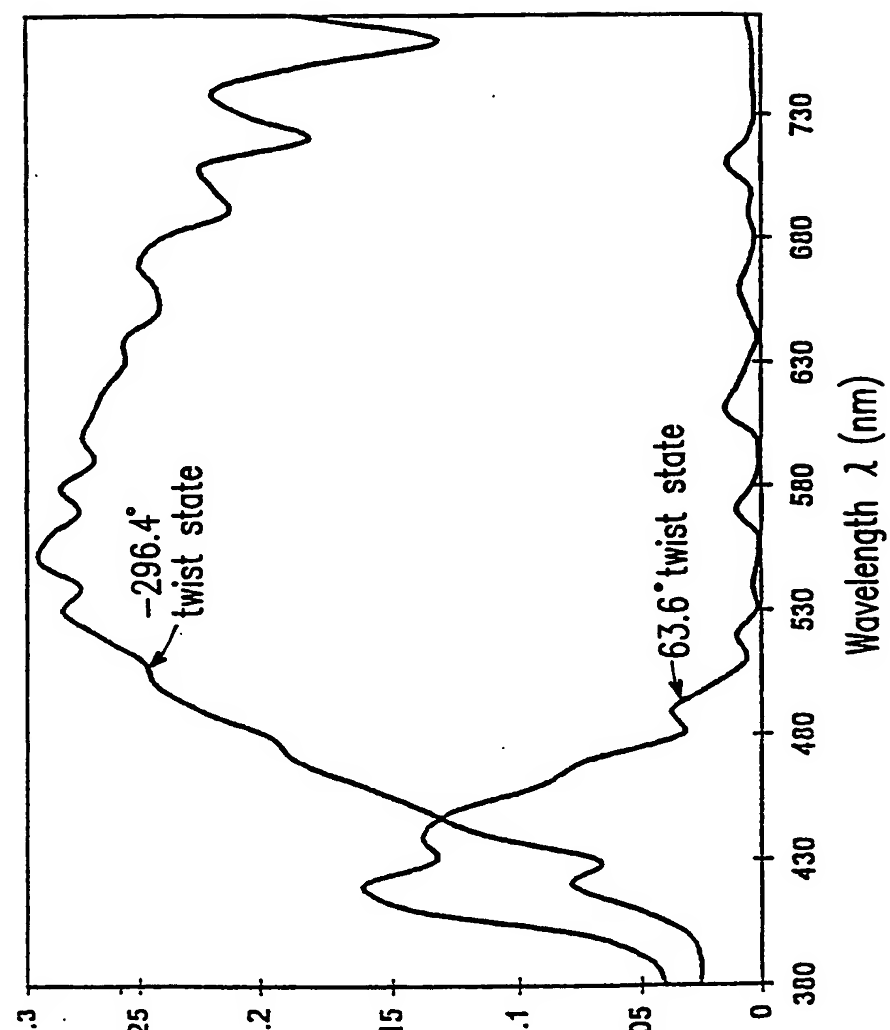

R
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)
−296.4° twist state
63.6° twist state

FIG. 17

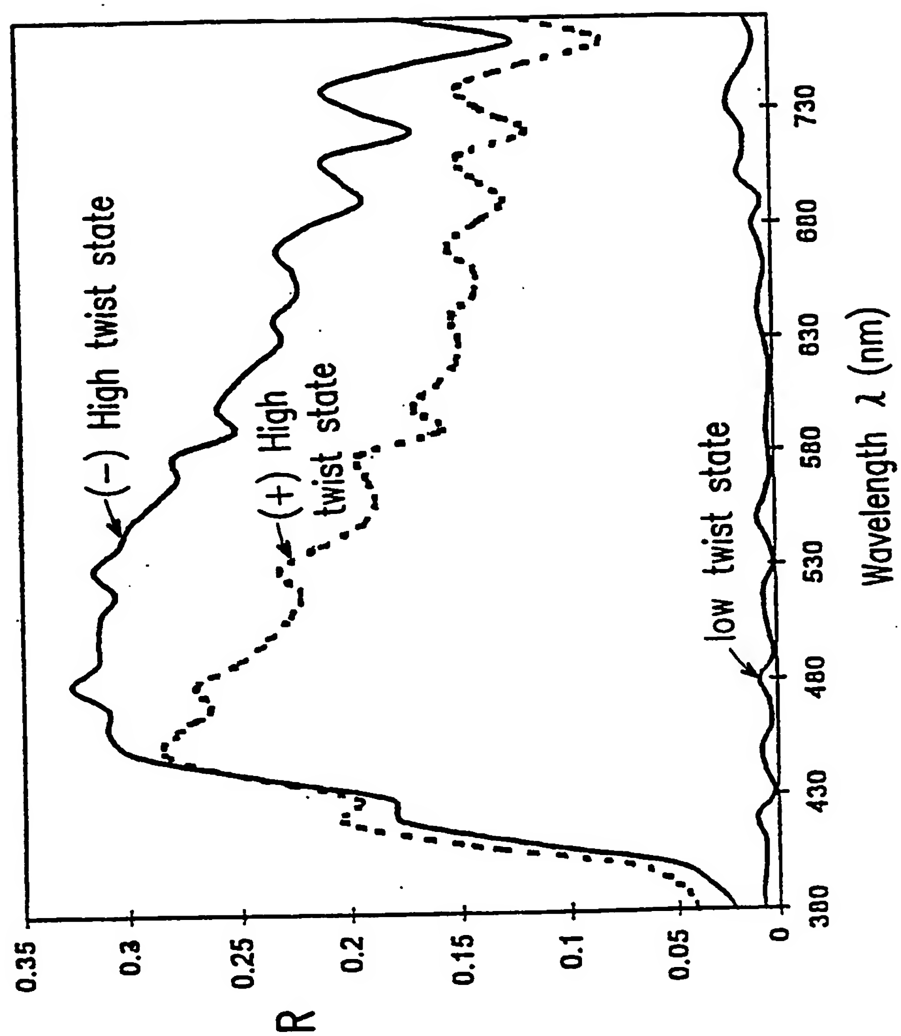

R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)
(−) High twist state
(+) High
twist state
low twist state

FIG.18

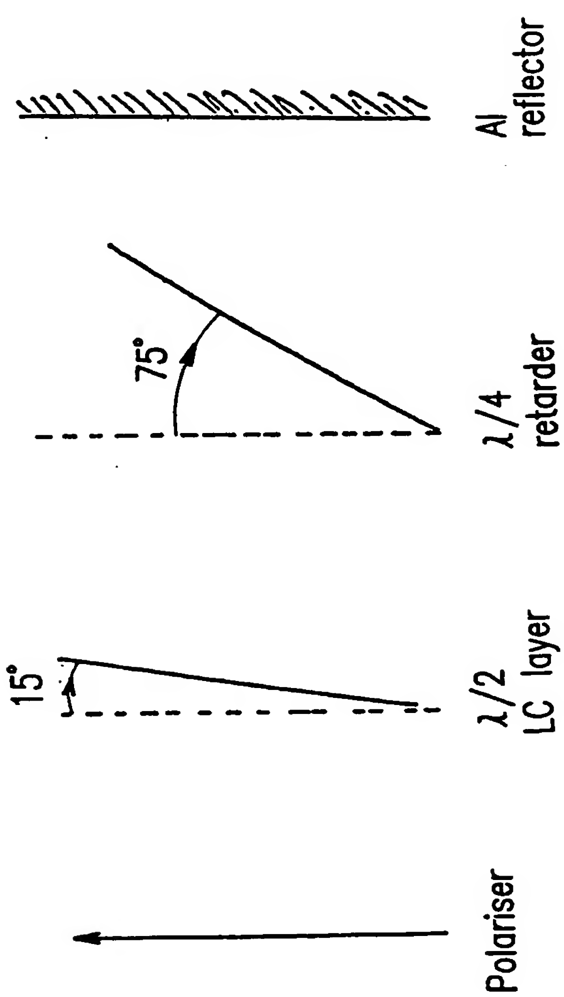
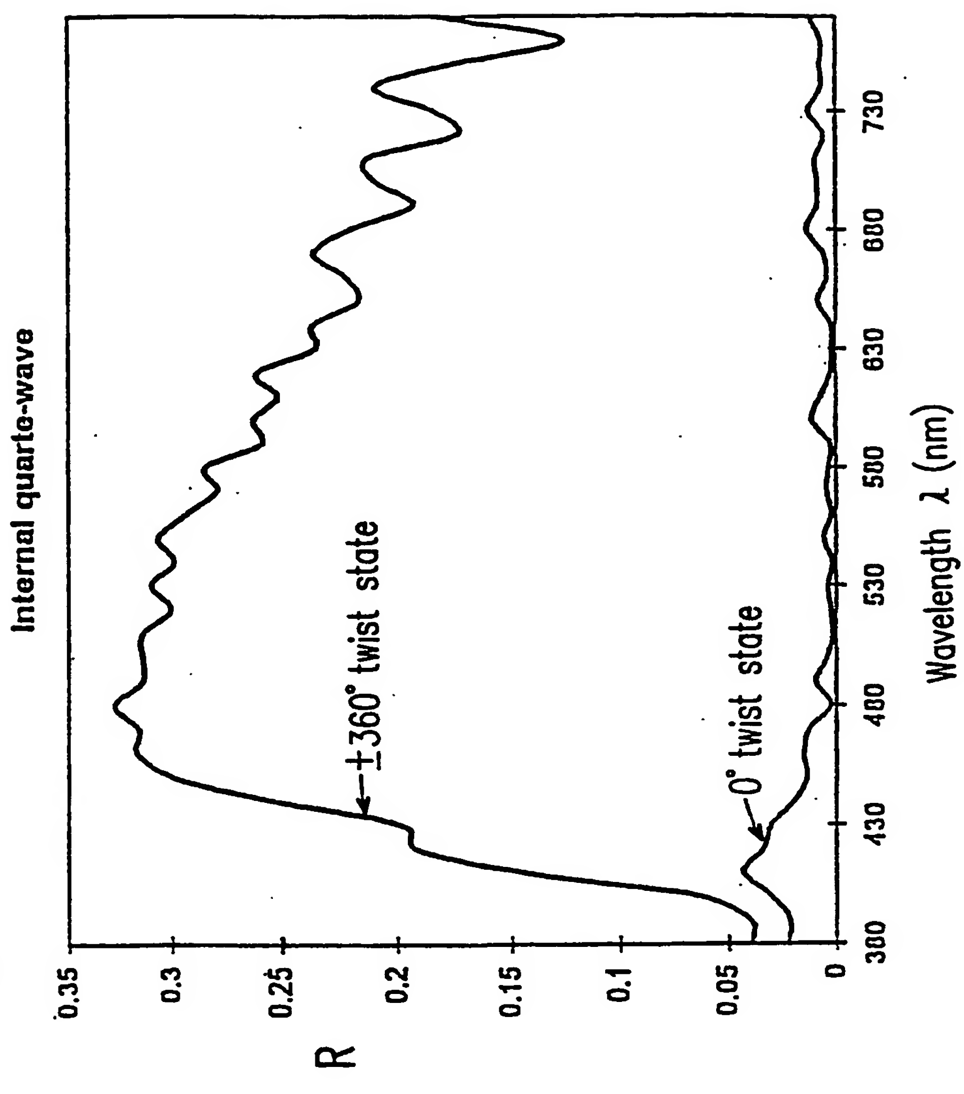


FIG. 19


Internal quarte-wave
±360° twist state
0° twist state
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)

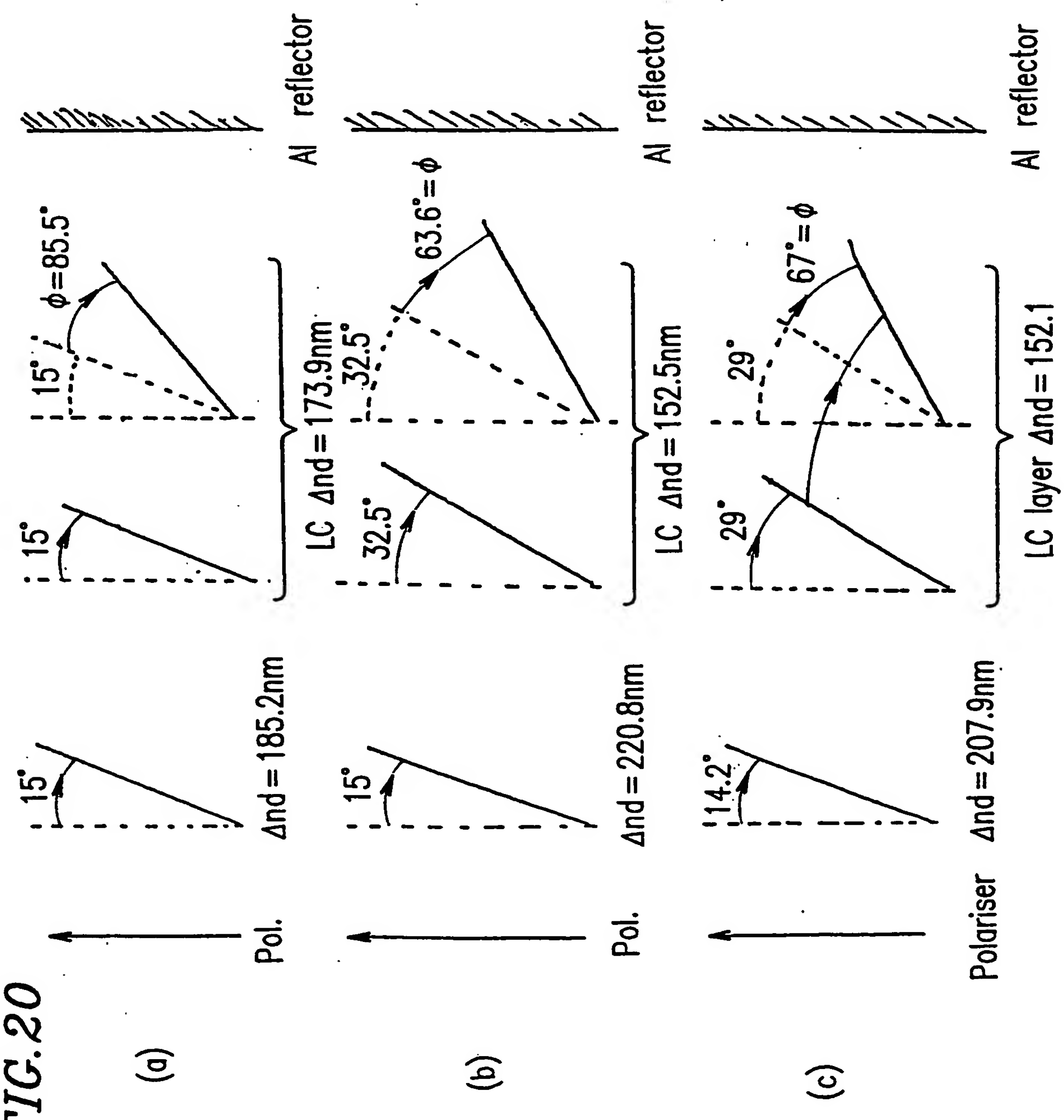
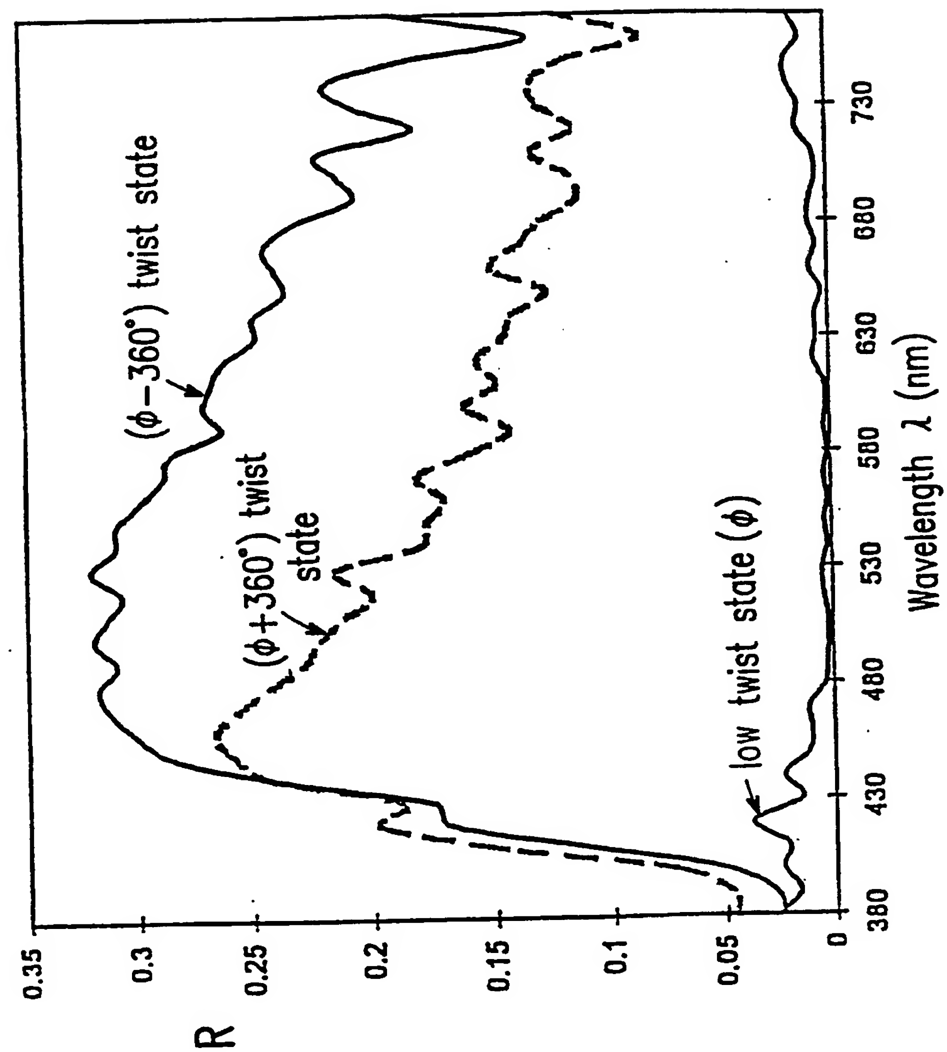

(a)
Pol.
15°
Δnd=185.2nm
15°
15°
ϕ=85.5°
LC Δnd=173.9nm
Al reflector
(b)
Pol.
15°
Δnd=220.8nm
32.5°
32.5°
63.6°=ϕ
LC Δnd=152.5nm
Al reflector
(c)
Polariser
14.2°
Δnd=207.9nm
29°
29°
67°=ϕ
LC layer Δnd=152.1
Al reflector

FIG.20



R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)
(φ−360°) twist state
(φ+360°) twist state
low twist state (φ)

FIG.21

FIG.22

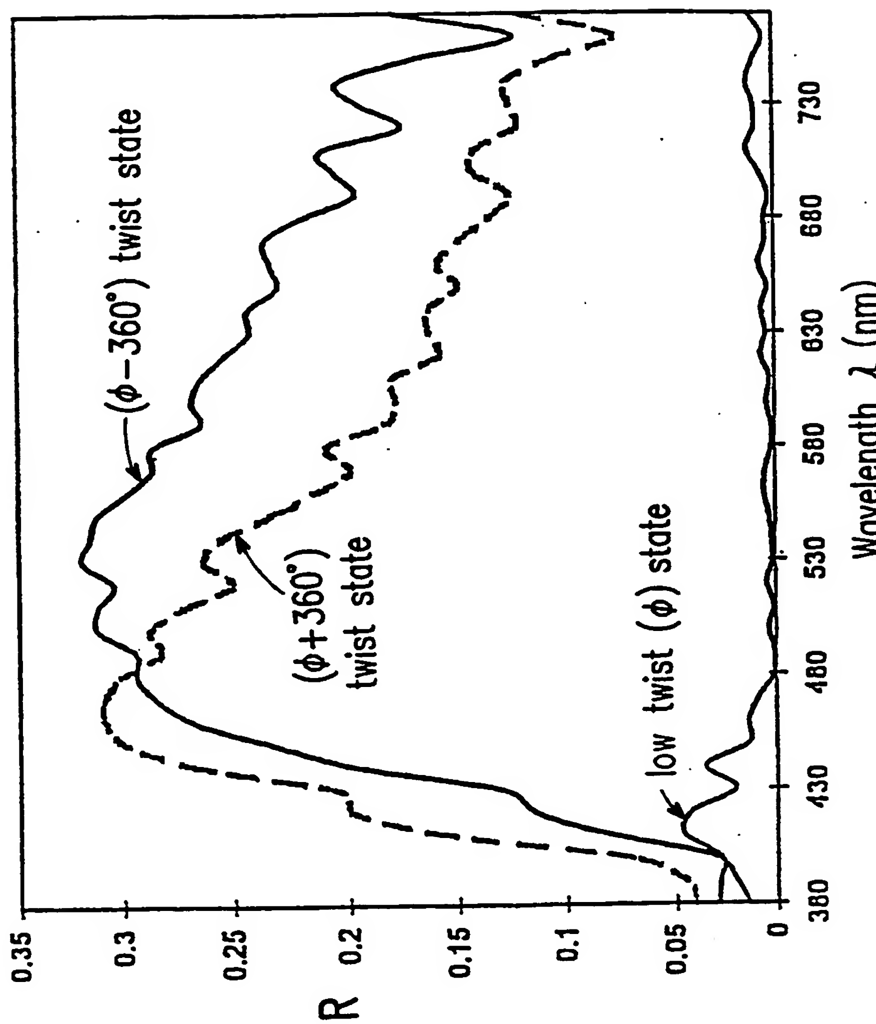
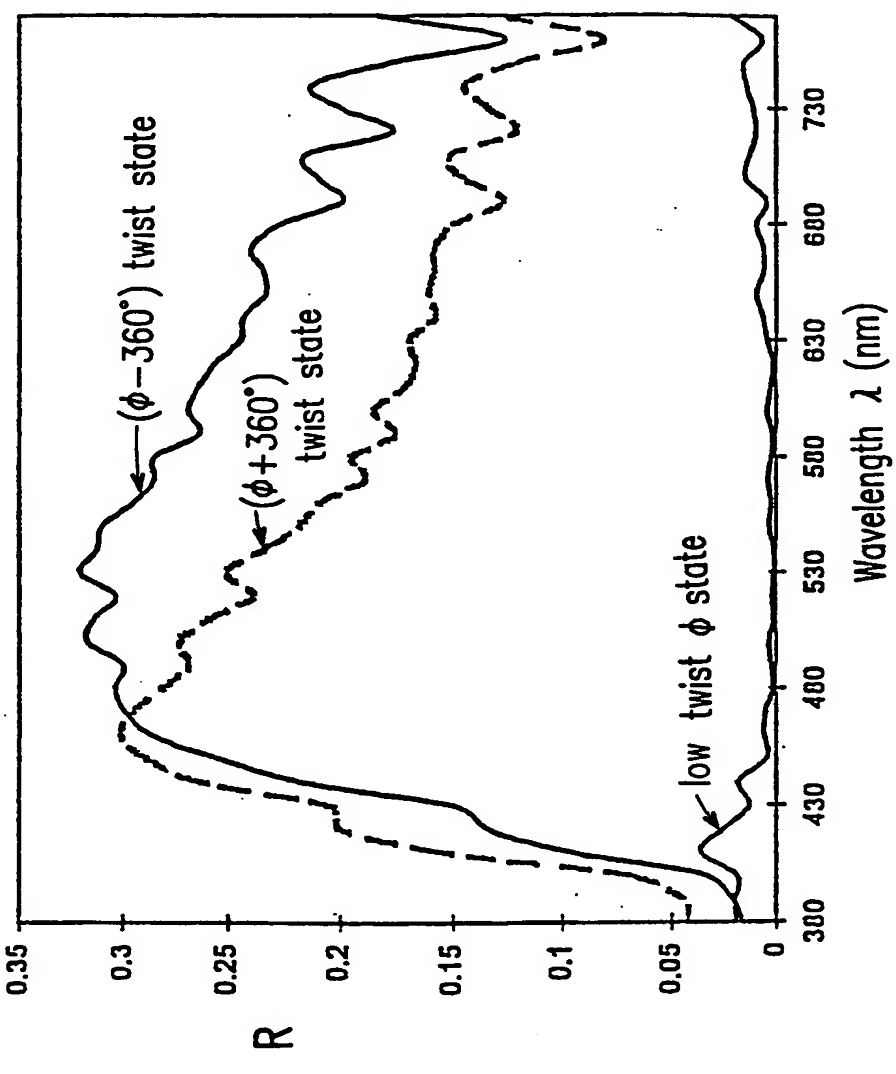

(ϕ−360°) twist state
(ϕ+360°) twist state
low twist (ϕ) state
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)

FIG.23


R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)
(φ−360°) twist state
(φ+360°) twist state
low twist φ state

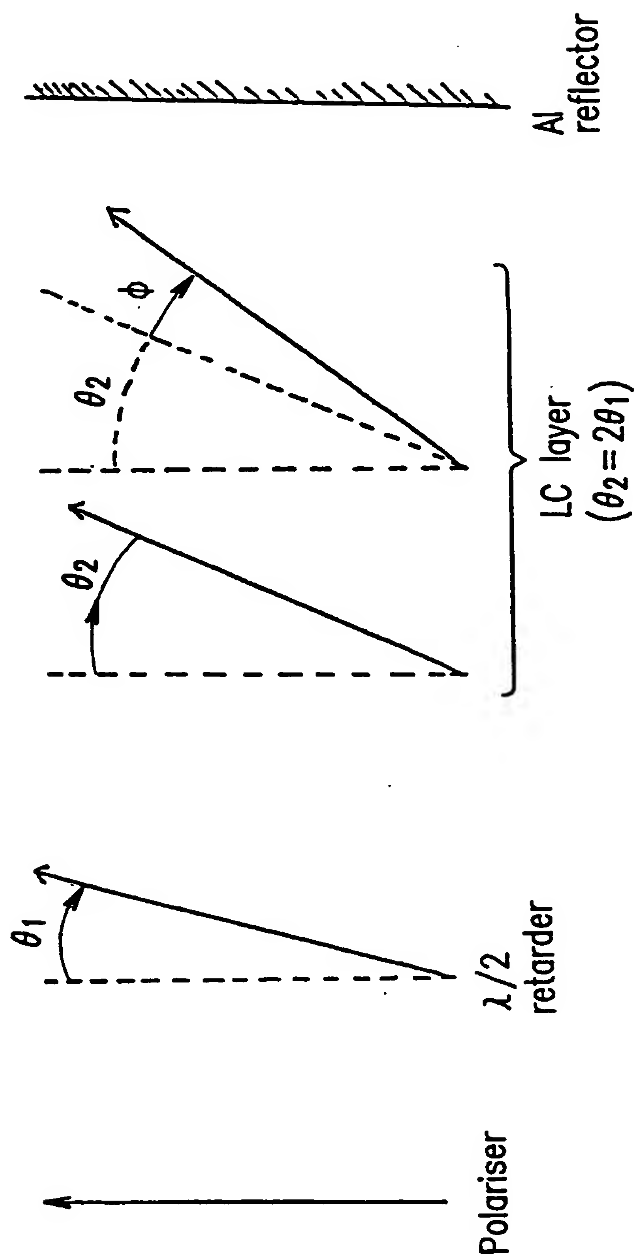

Polariser
$\lambda/2$ retarder
θ_1
θ_2
θ_2
ϕ
LC layer
$(\theta_2 = 2\theta_1)$
Al reflector

FIG.24

FIG.25

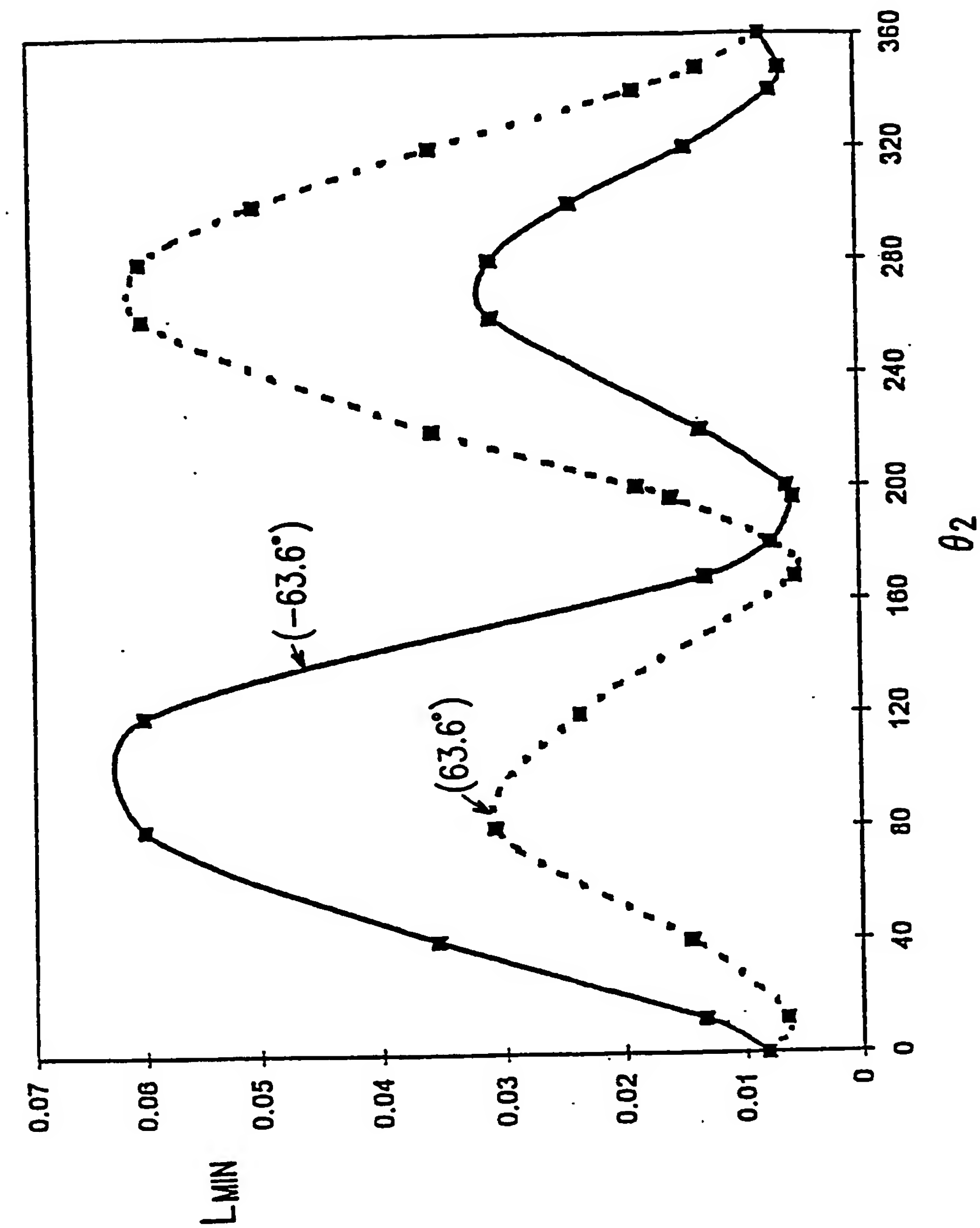

LMIN
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
40
80
120
160
200
240
280
320
360
θ2
(−63.6°)
(63.6°)

FIG.26

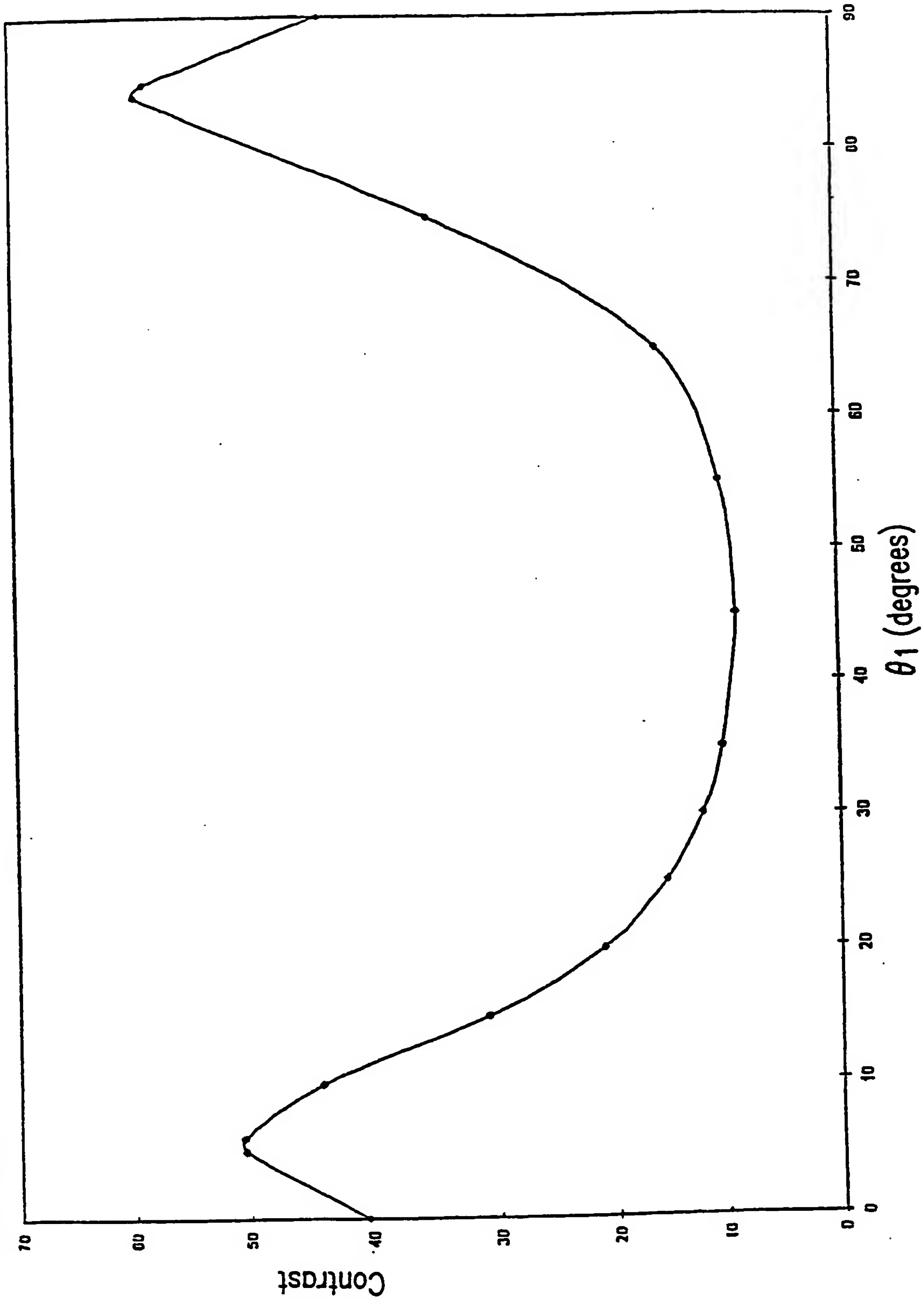


FIG.27

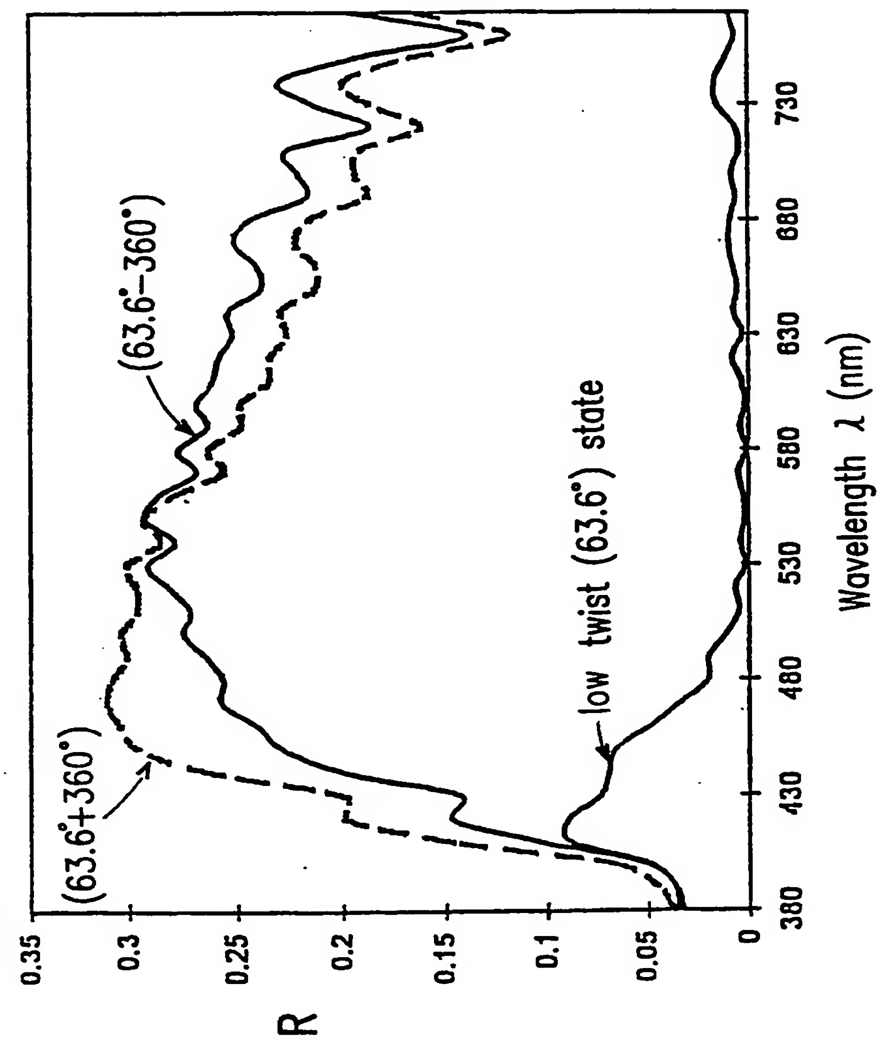

R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
380
430
480
530
580
630
680
730
Wavelength λ (nm)
(63.6°+360°)
(63.6°-360°)
low twist (63.6°) state

FIG.28

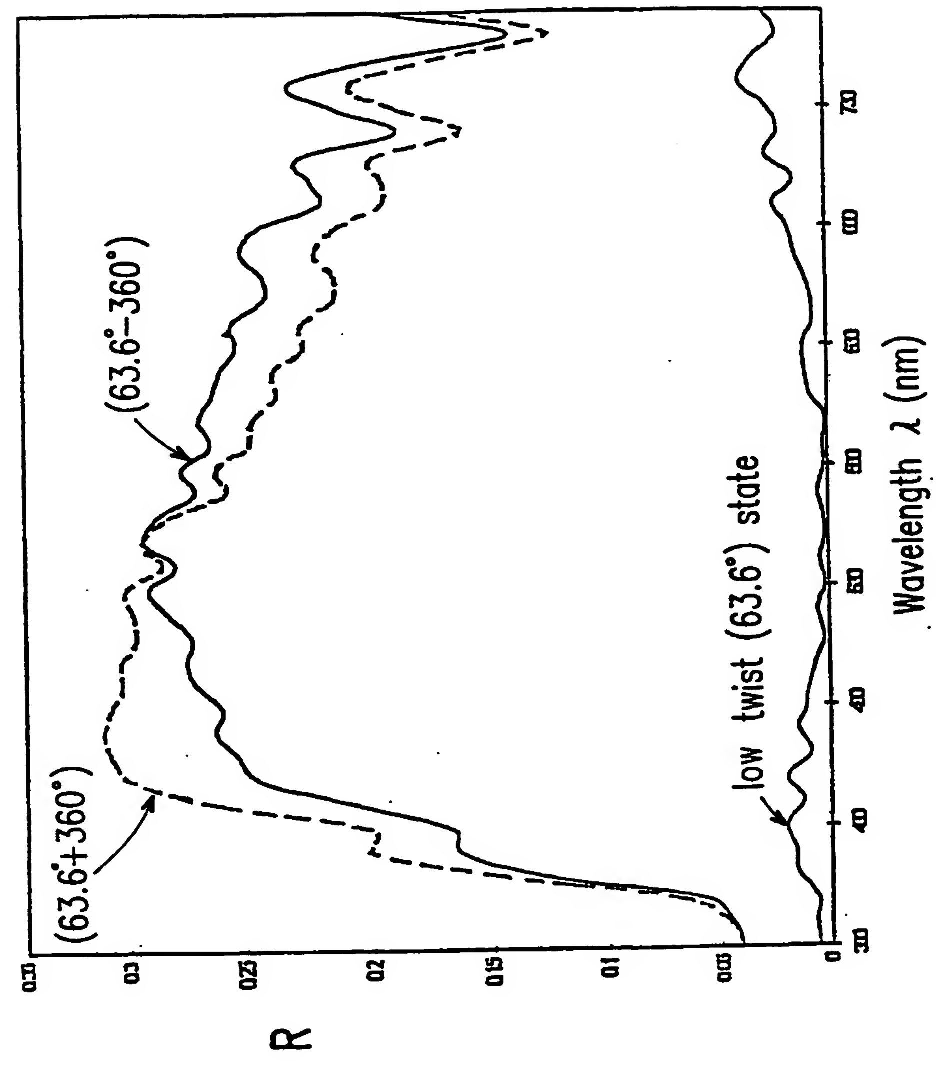


FIG.29

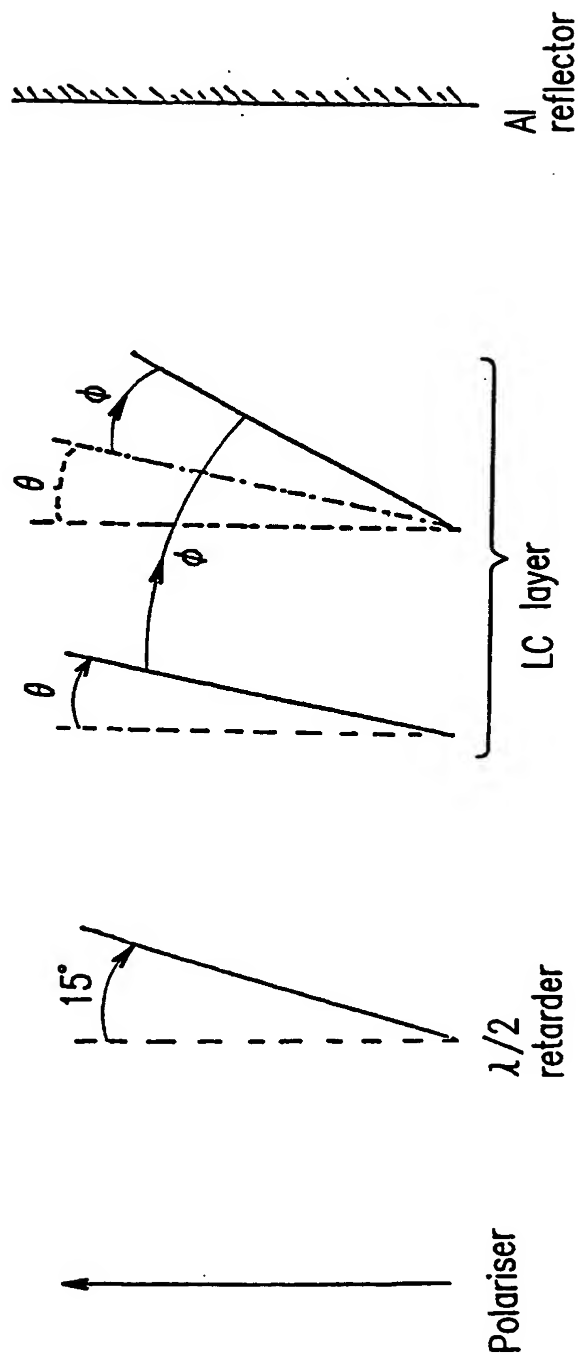


FIG. 30

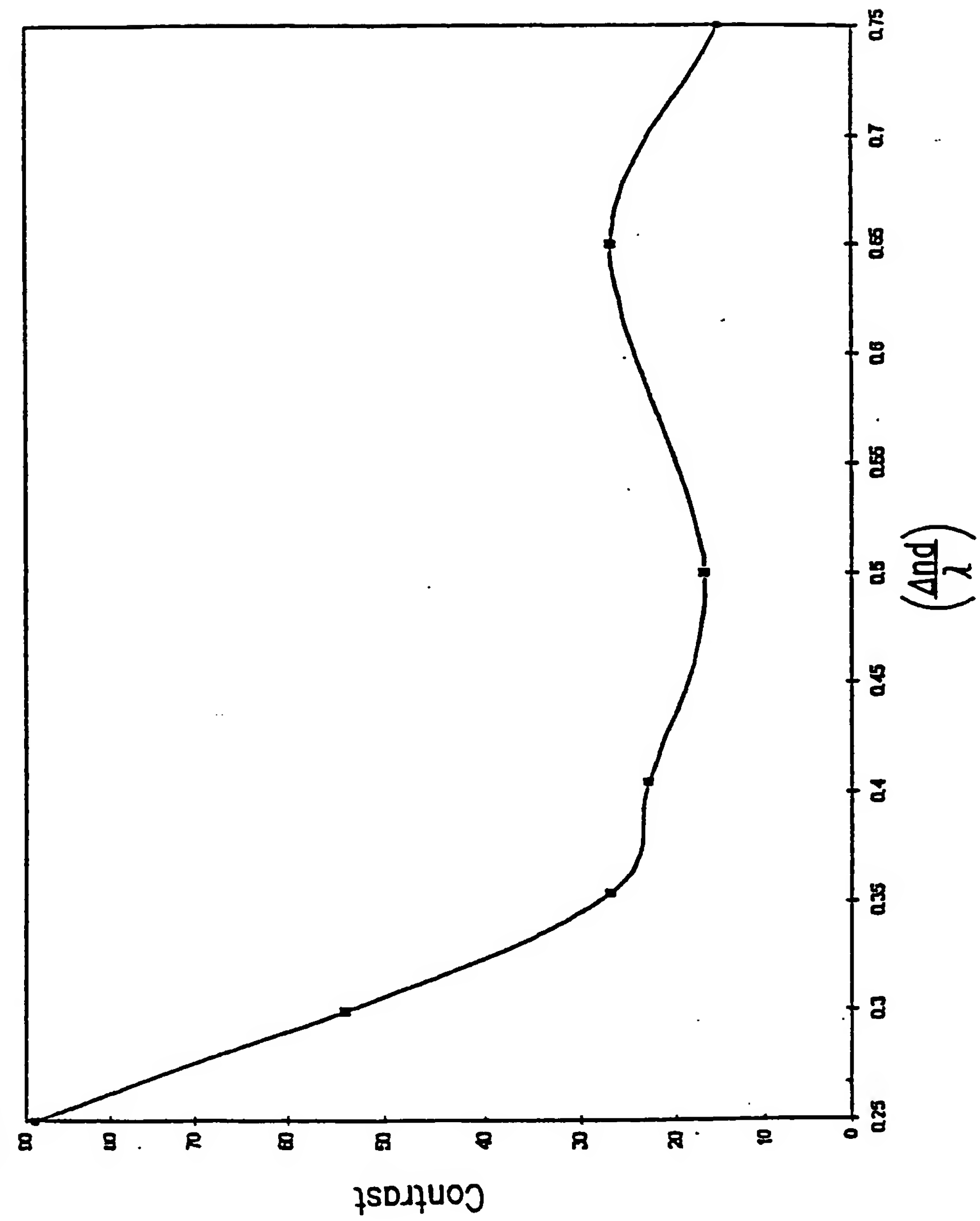
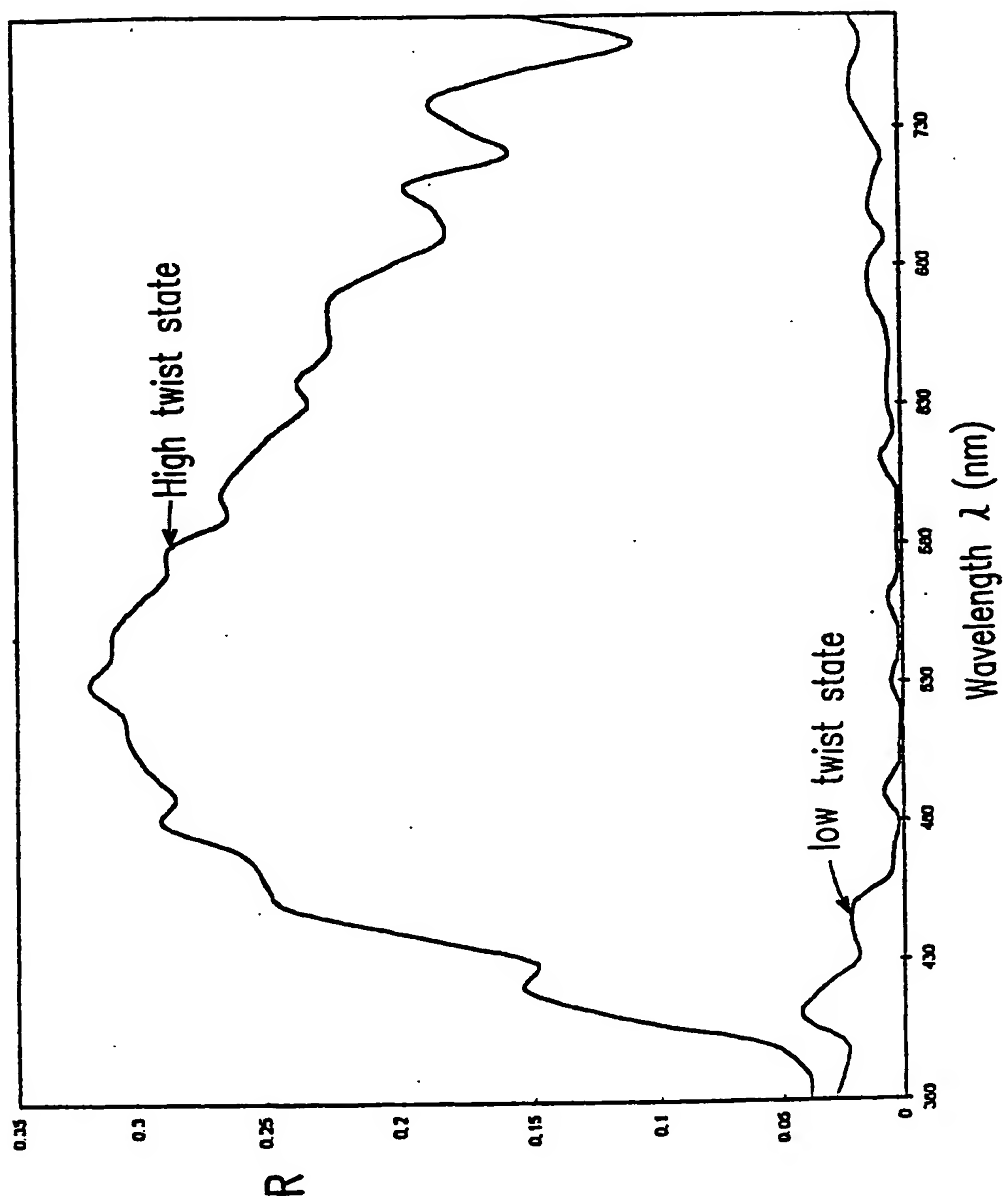

Contrast
0
10
20
30
40
50
60
70
80
90
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
$\left(\frac{\Delta nd}{\lambda}\right)$

FIG.31



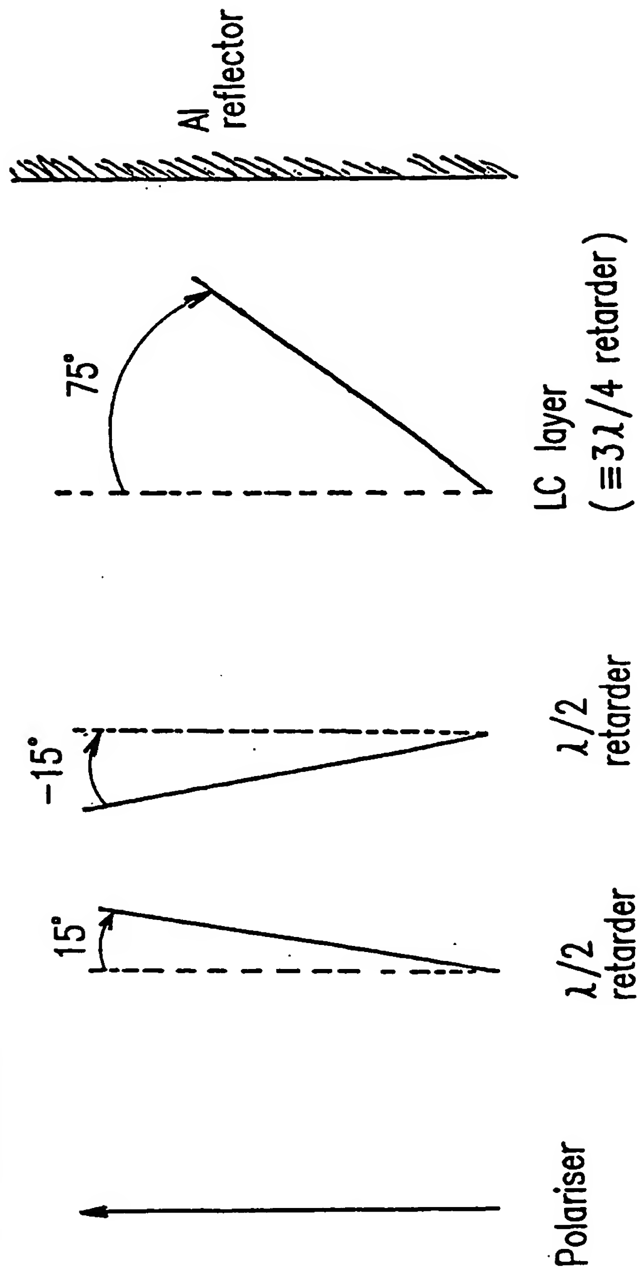
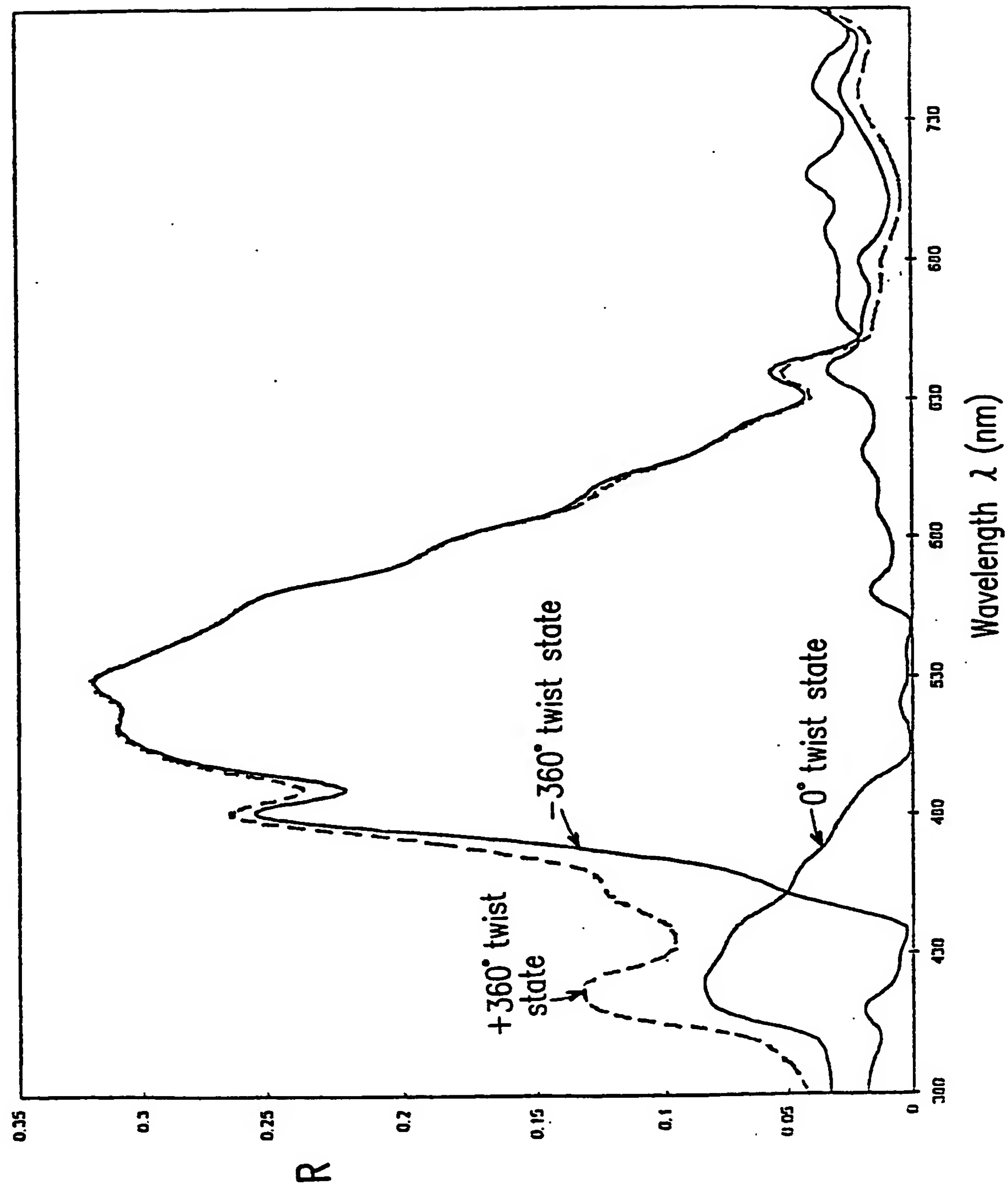

Al
reflector
75°
LC layer
(≡3λ/4 retarder)
-15°
λ/2
retarder
15°
λ/2
retarder
Polariser

FIG.32

FIG.33


R
Wavelength λ (nm)
+360° twist state
−360° twist state
0° twist state

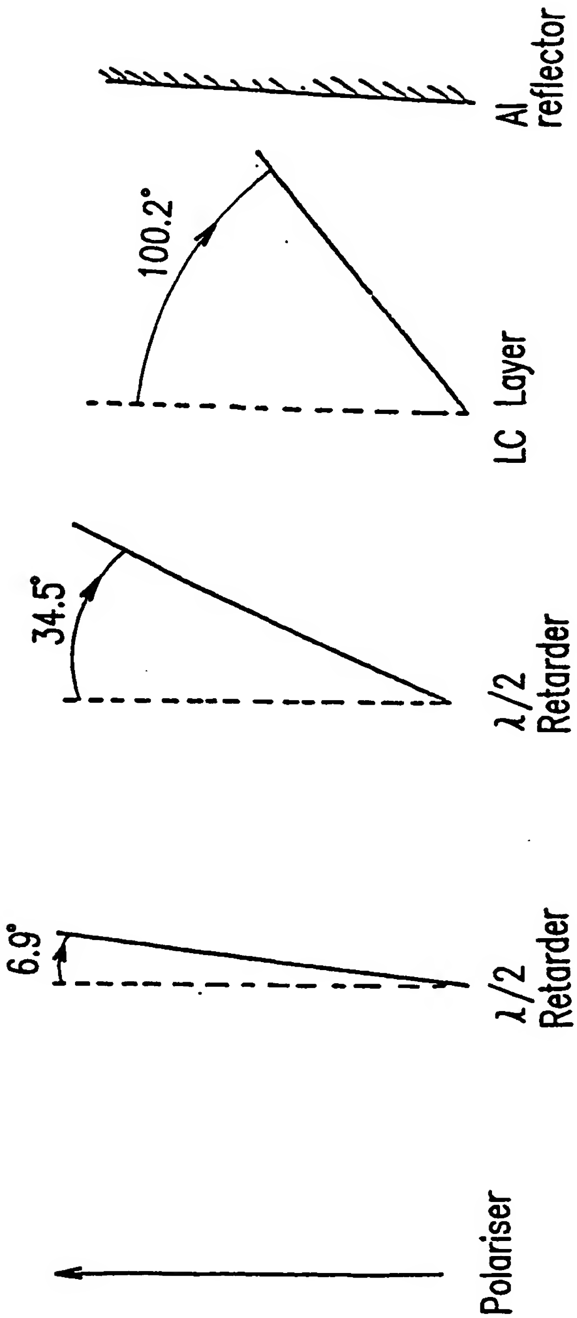

Al
reflector
100.2°
LC Layer
34.5°
λ/2
Retarder
6.9°
λ/2
Retarder
Polariser

FIG. 34

FIG.35

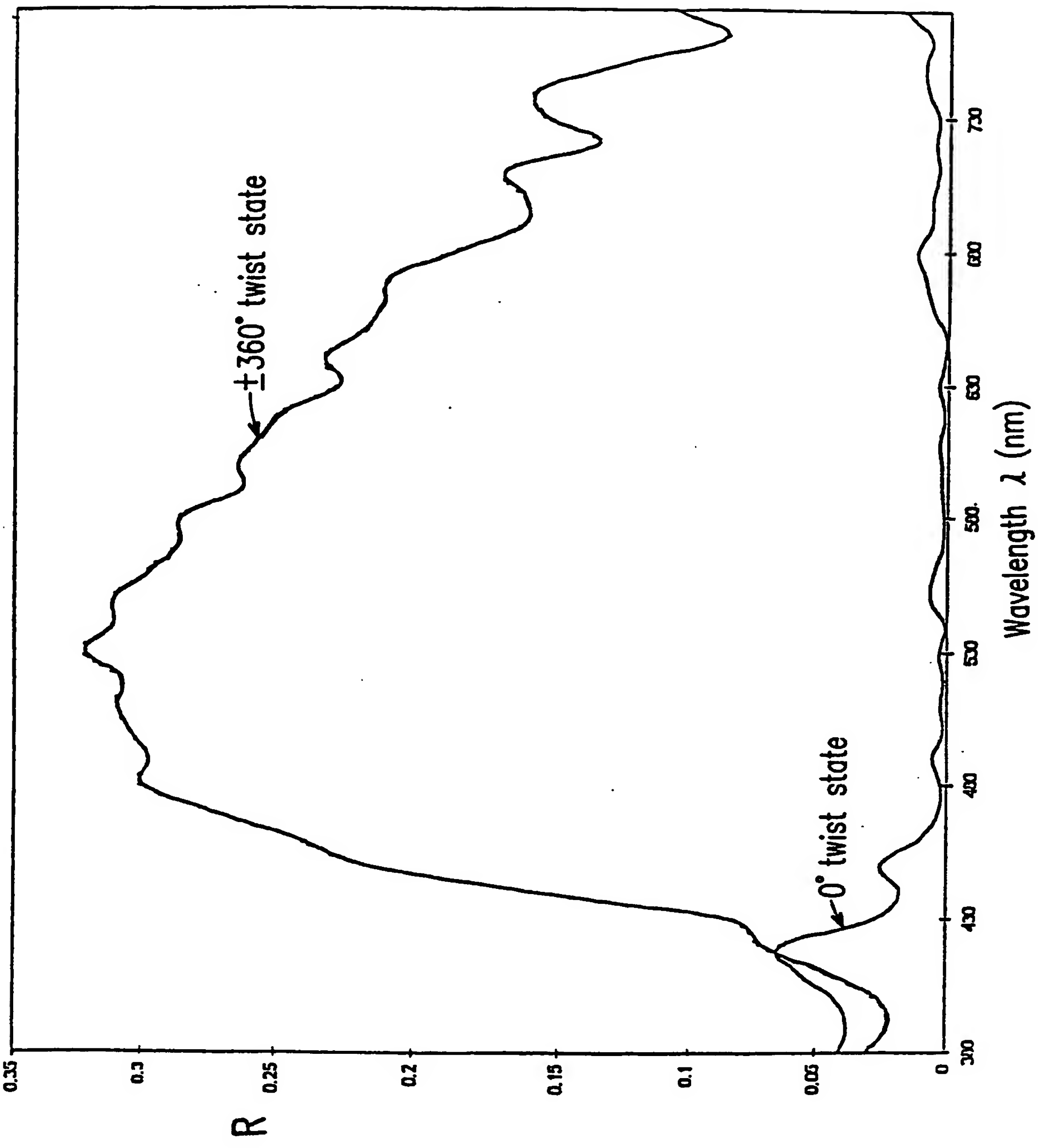

±360° twist state
0° twist state
Wavelength λ (nm)
R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

FIG.36

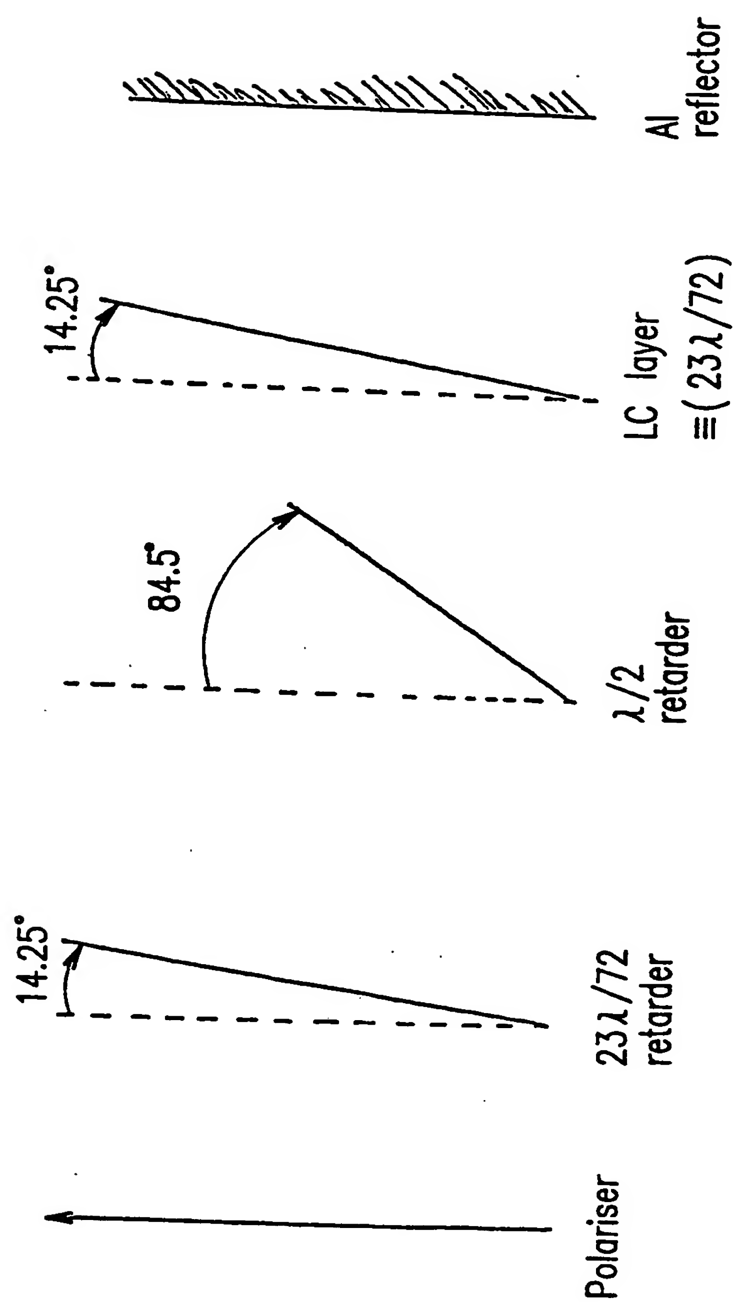
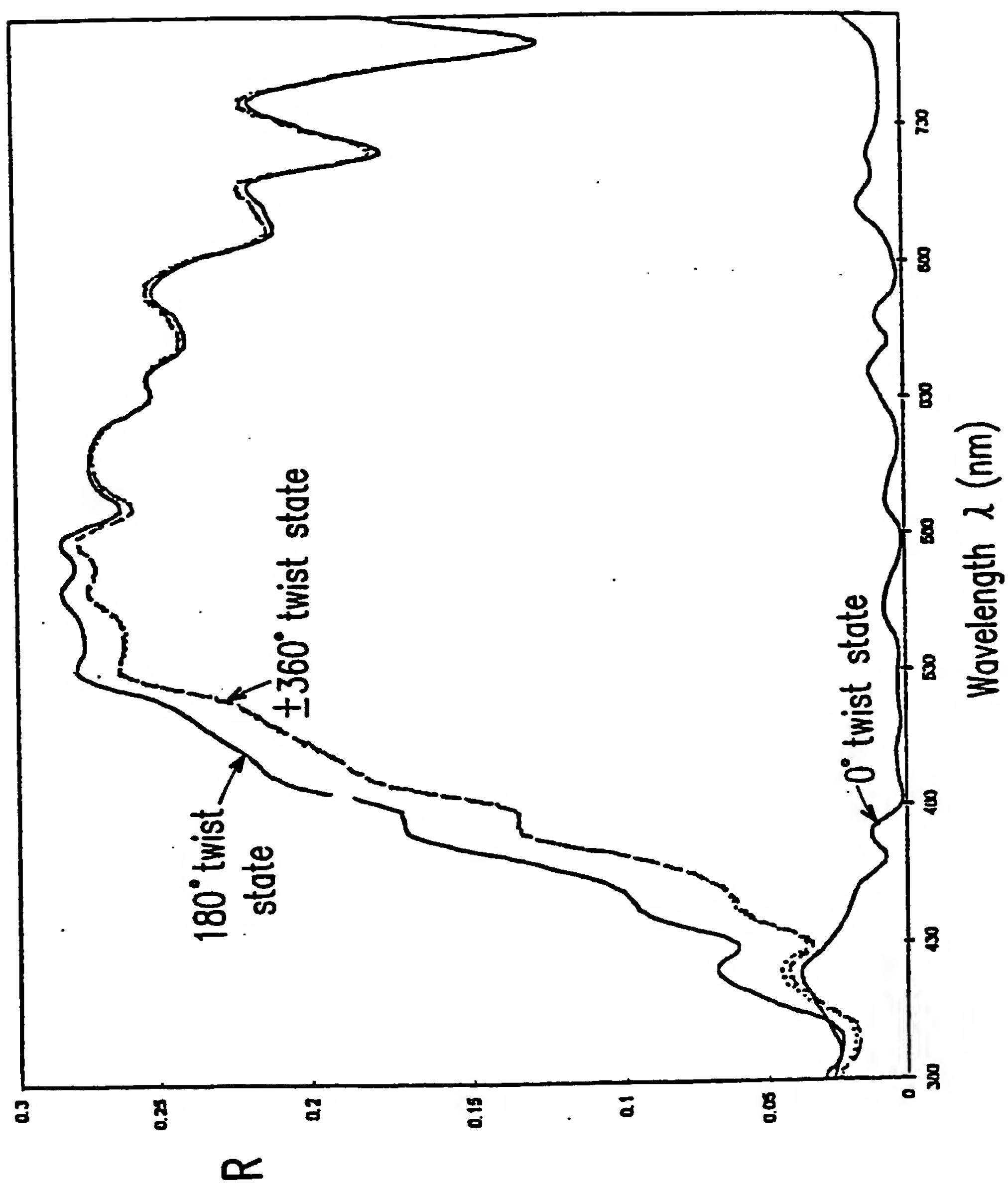

Polariser
14.25°
23λ/72
retarder
84.5°
λ/2
retarder
14.25°
LC layer
≡(23λ/72)
Al
reflector

FIG.37


R
0.3
0.25
0.2
0.15
0.1
0.05
0
180° twist state
±360° twist state
0° twist state
Wavelength λ (nm)

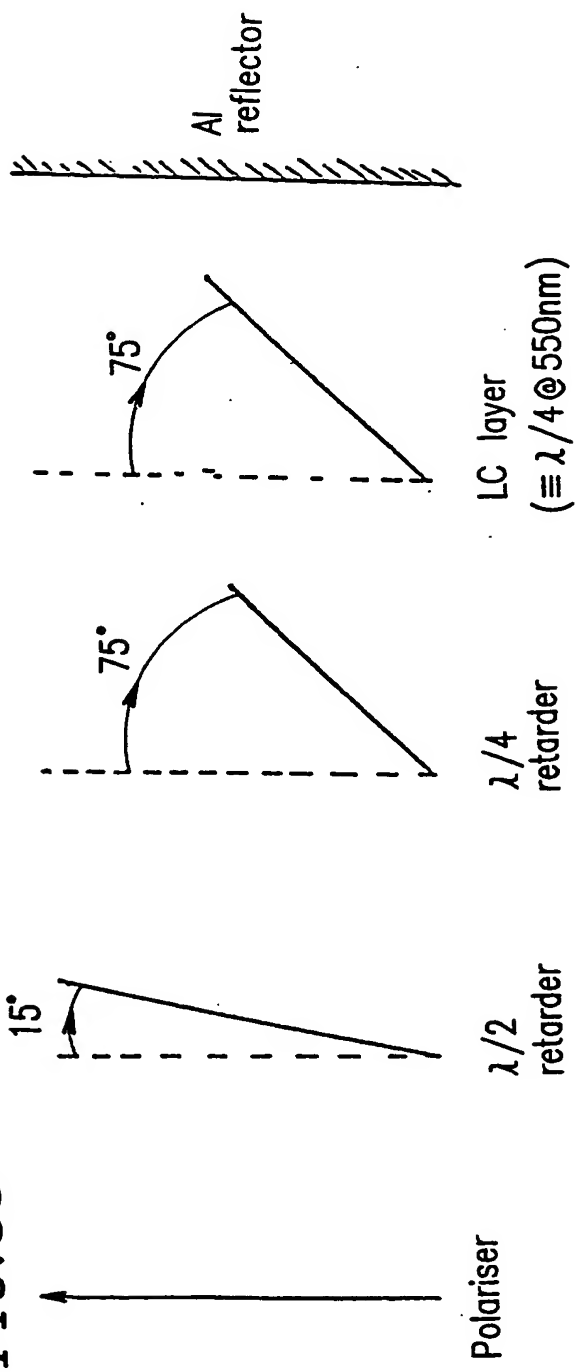
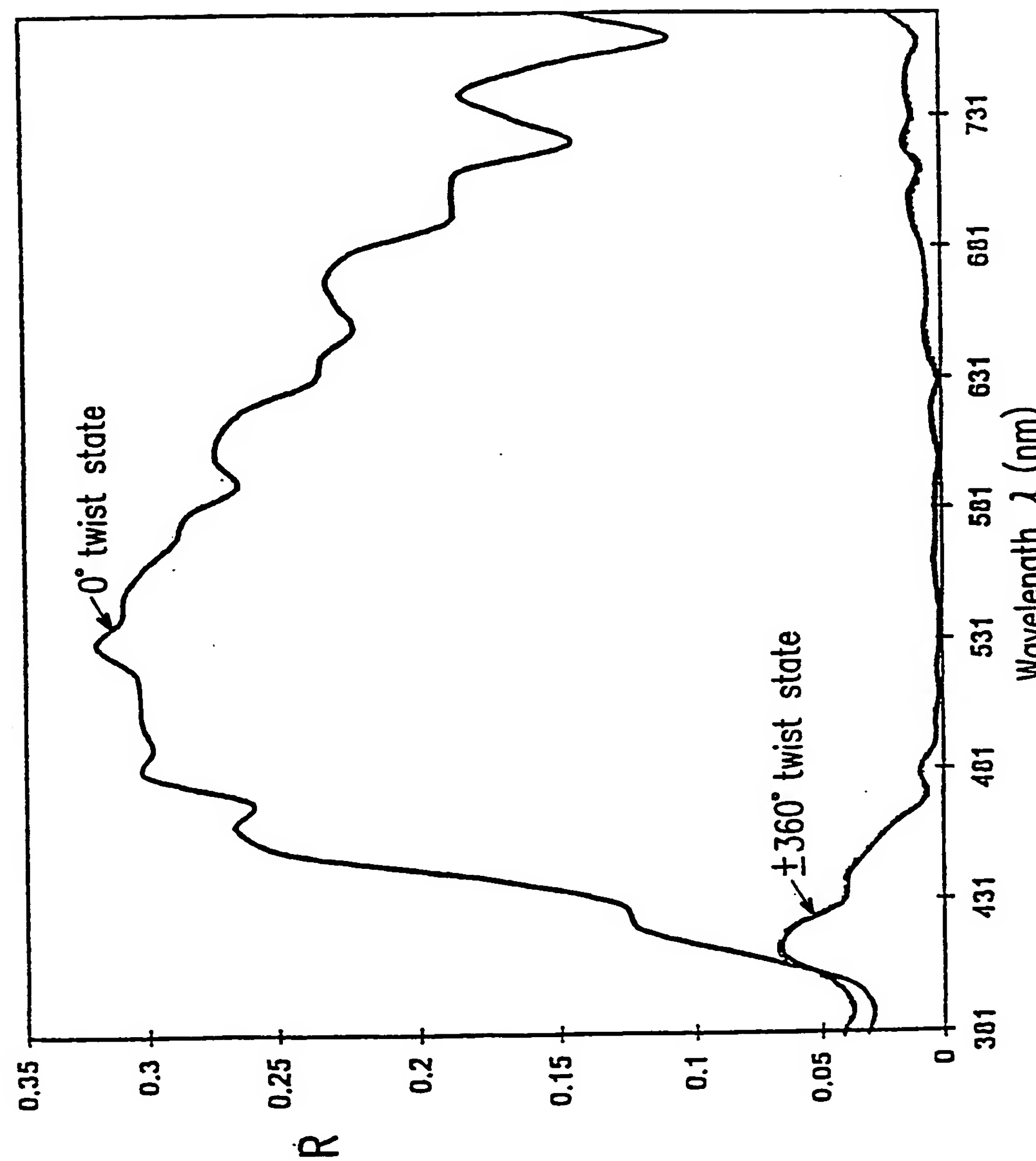

Al
reflector
75°
LC layer
(≡ λ/4 @ 550nm)
75°
λ/4
retarder
15°
λ/2
retarder
Polariser

FIG. 38

FIG. 39


R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
301
431
481
531
581
631
681
731
Wavelength λ (nm)
0° twist state
±360° twist state

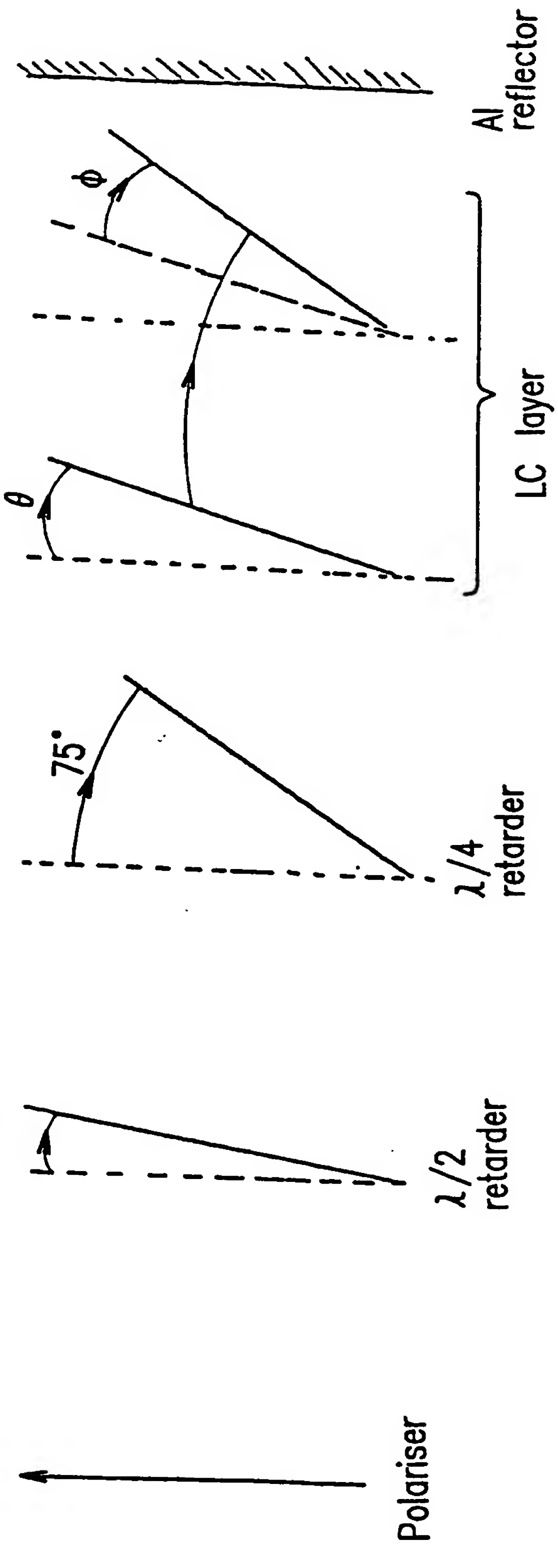

Al
reflector
ϕ
θ
LC layer
75°
$\lambda/4$
retarder
15°
$\lambda/2$
retarder
Polariser

FIG. 40

FIG. 41

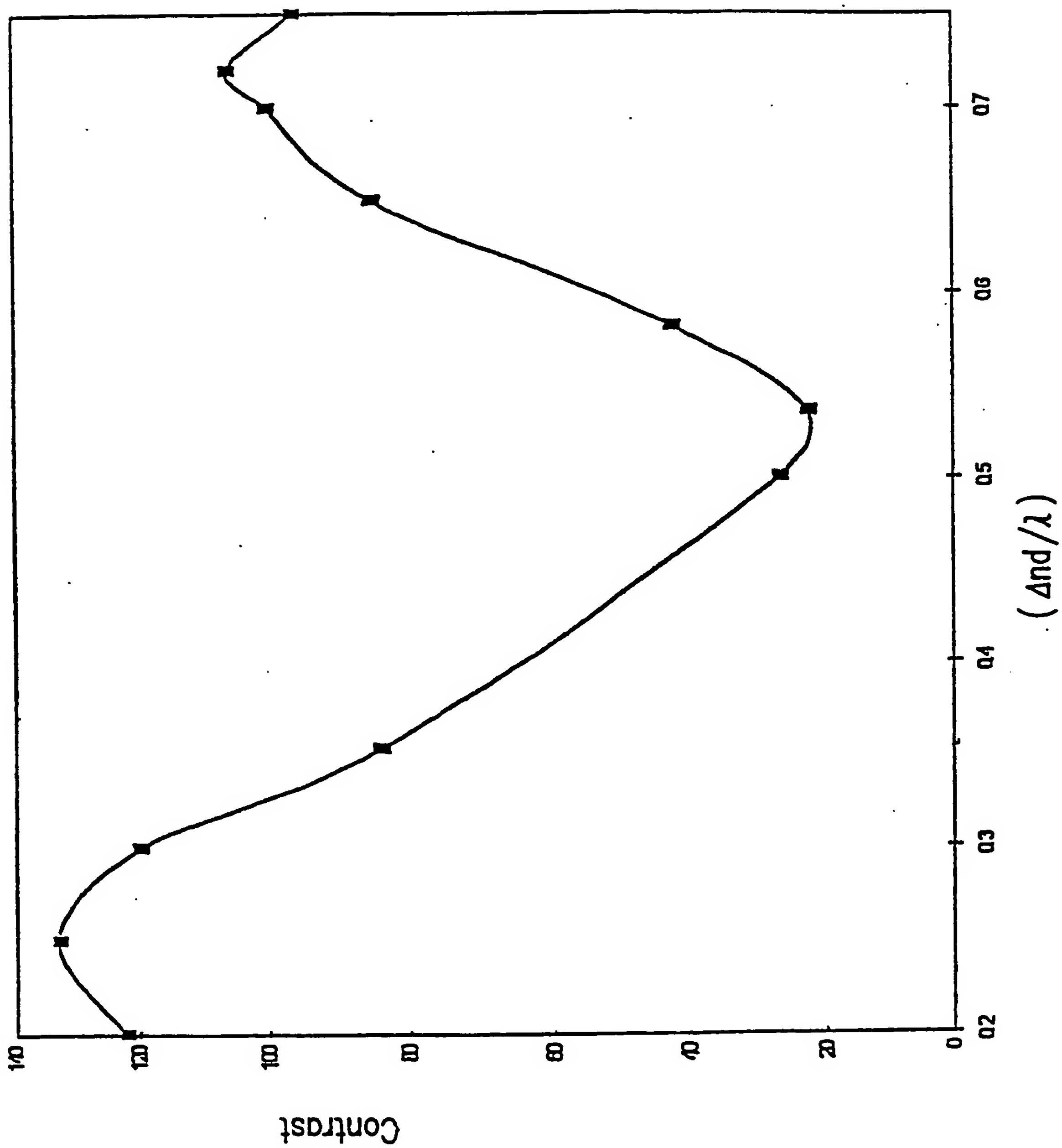


FIG. 42

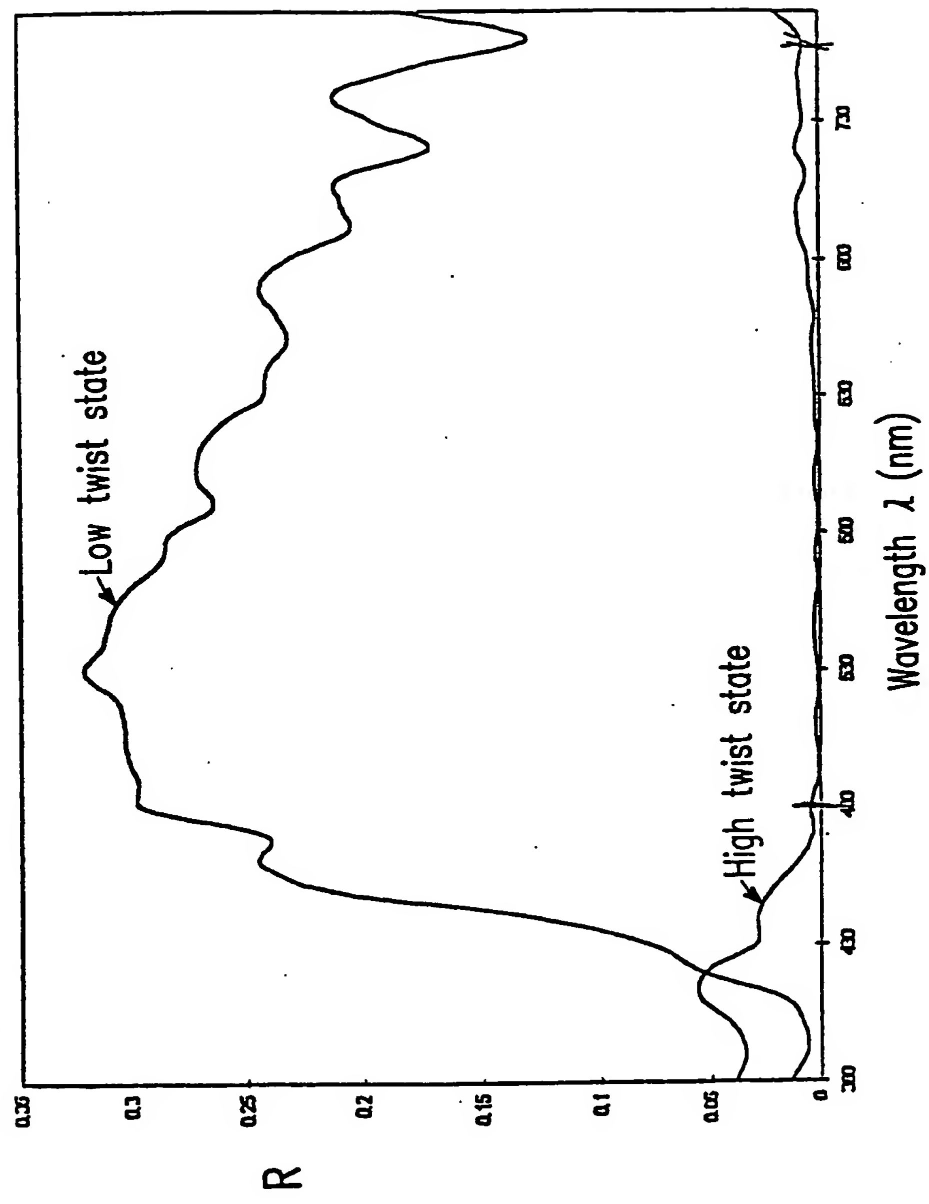

R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Low twist state
High twist state
Wavelength λ (nm)

FIG. 43

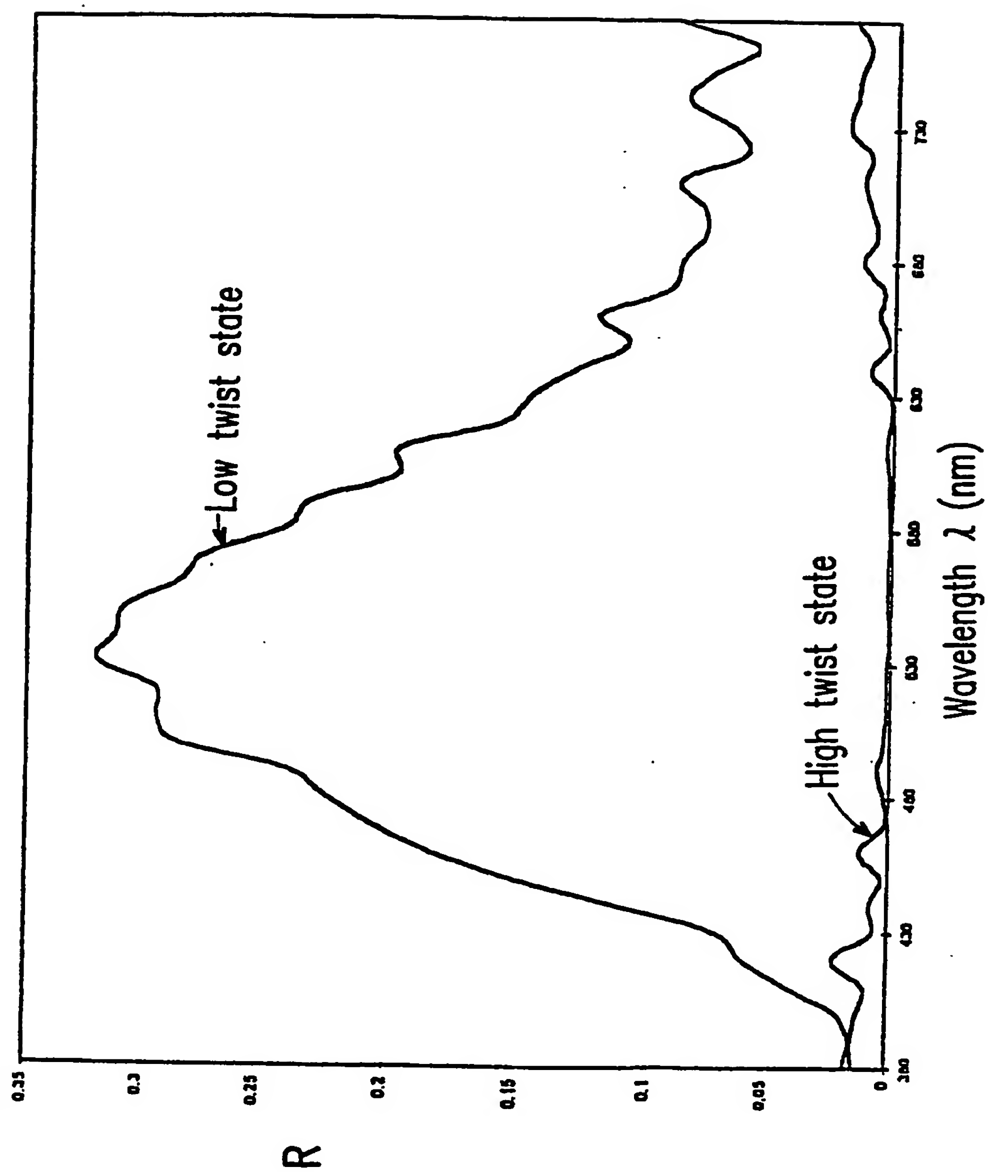
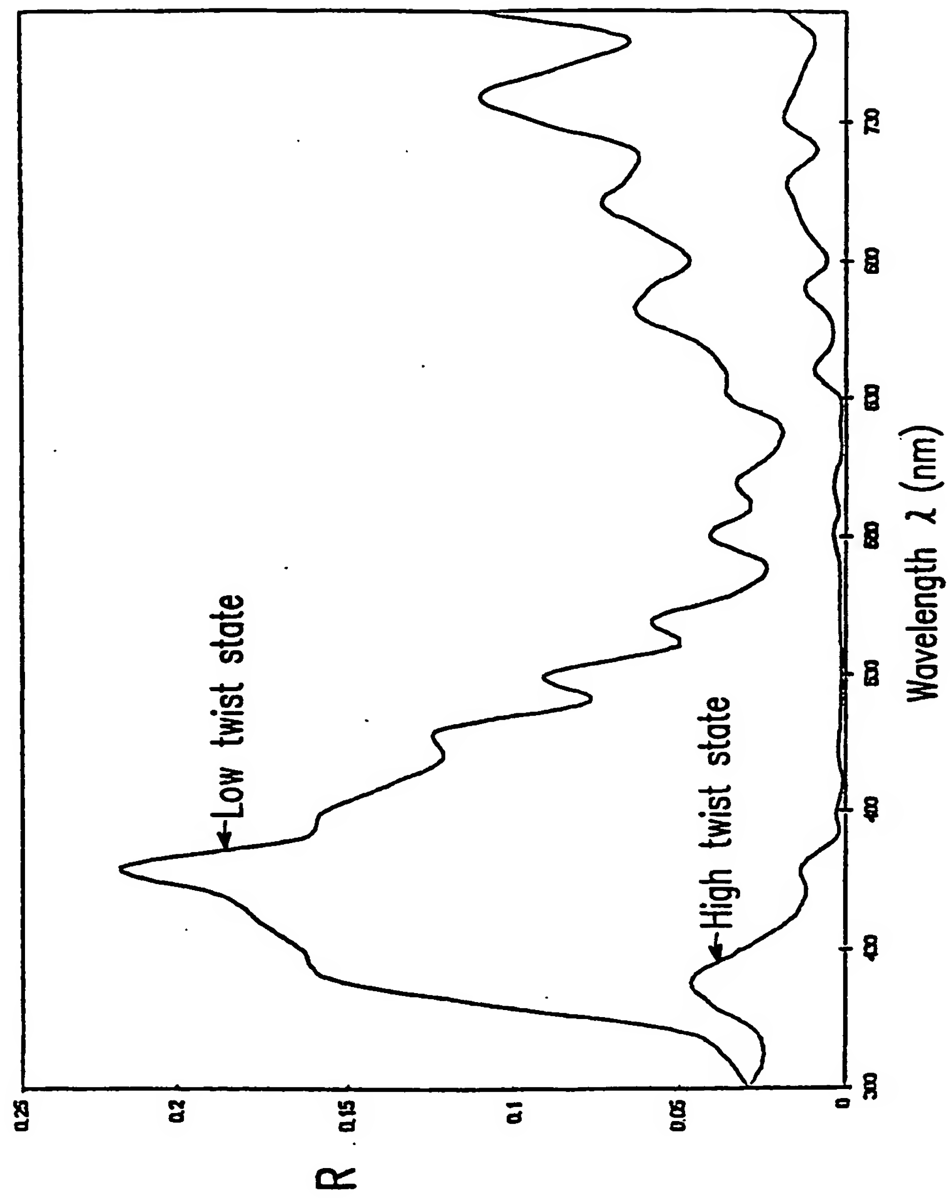

R
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Low twist state
High twist state
Wavelength λ (nm)

FIG. 44


Low twist state
High twist state
R
0.25
0.2
0.15
0.1
0.05
0
300
Wavelength λ (nm)